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FIRST PRINCIPLES
OF
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3

FIRST PRINCIPLES

OF

ELECTRICAL ENGINEERING:

*Being an attempt to provide an Elementary Book
for those who are intending to enter the
profession of Electrical Engineering.*

BY

C. H. W. BIGGS,
Editor of "The Electrical Engineer."

Illustrated.

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DEDICATION.

THERE is no living Electrician whom I admire more than Prof. D. E. Hughes, F.R.S., and to him I would fain dedicate this little volume, as a mark of the esteem in which I hold him.

C. H. W. BIGGS.

PREFACE.

The usual formula of writers is that their productions "supply a want." In my case I do not know that there is a want to supply. Of elementary books on electrical subjects there is no end, and in the majority of cases when they have been read and studied, the readers find the sooner the contents are forgotten the better. There has been a cry among the authors of technical books that practical application of principles is for others—for them the only objective is "principles." This shows Carlyle's estimation of the world was strictly true, it consists of wise men and fools—mostly fools. The discussions of so-called principles in the schoolbooks occupy perhaps one per cent. of their pages, a large part is filled with the description of experiments of antediluvian origin, descriptions that can without difficulty be traced backwards through most of the books written during the past century. The remainder of the pages of the books contains "examples," examples to be worked in class, or for preparation for some examination; examples that savour of the ridiculous, not to say the ludicrous, of no earthly use to the solvers either as practical applications or as mental gymnastics. These views are those of a cynic as regards the majority of schoolbooks, and no doubt this display of cynicism will meet with its reward from the reviewers. A few words more for the edification of these gentlemen will probably raise their ire still further. The reviews of technical books written in the ordinary and so-called literary papers are a disgrace to journalism. In ninety-nine cases out of a hundred they are evidently written by literary hacks, who have no more knowledge of the subject treated in the book than they have of the inhabitants of Jupiter, and yet school books and technical books are damned or praised by these ignoramuses. A book that is not upon the old conservative lines of their boyhood is put outside the pale—it is heterodox; as if they knew the difference between heterodoxy and orthodoxy. Well, these men will have a chance to say their say in regard to this book. It certainly does not follow old lines, it certainly has not the imprint of authority for all its digressions, it is not put forward as perfect,—far from it. The book has been written at odd times, laid aside sometimes for months, and then a portion added.

The author's contention is that all electrical and magnetic problems can be discussed in their relation to the conductive and the magnetic circuits and the interactions of these circuits. He has not rigidly adhered to his own views, but has interpolated in the text a third circuit, the inductive; which, however, he believes has no existence in fact whatever it may have in fancy, and however useful it may be as a convention. Again, the author believes the ordinary definition of unit magnetic pole to be utterly and radically incorrect; yet he has accepted it, thongh another definition of unit pole would greatly simplify calculations. "A unit pole" the author would define "as a pole caused by one or unit line of force."

The aim is not to explain what electricity is, or what it is not, but to give a working foundation to students whose hope is to become practical men. The difficulty has been in a little work of the kind intended for beginners and beginners only, to decide what should go in and what should be left out. It may serve as an introductory study to the writings of Hopkinson, Kapp, Thompson, and other specialists.

There is very little in the book that will clash with the views of workers like Crompton, Esson, D. FitzGerald Hering, Hughes, Hopkinson, Kapp, Mordey, Preece, Reckenzaun, Sellon, Swinburne, Thompson and others, whose views are more toward the practical than the theoretic. The hack writers whose forte is writing school-books, will probably show no mercy, they need feel no qualms about it, for the author will be only too glad to have the advantage of their criticisms and the opportunity of answering them. That he has made mistakes no one knows better than himself, and no one will be better pleased to have such mistakes pointed out. It is not the fear of making mistakes he detests, it is the humdrum dry-as-dust unpractical and thoughtless iteration of Thales, rubbed amber, the dry and 4,250 other piles or batteries that writers of elementary books "for school and college work," are so fond of harping upon. Better make mistakes in attempting a book on fresh lines than run on for ever on the old route, especially when the old route does not lead to accord with the foremost thinkers and workers of to-day.

There is no attack or disparagement meant in regard to theorists like Sir W. Thomson, Clerk Maxwell, Profs. Lodge, Rowland, etc. They do not write elementary books for beginners in the study of electrical engineering. They are giants whom we admire afar off. To repeat again, the theorists we refer to, are the authors of all the elementary schoolbooks in existence, except perhaps three, and these three would be the better for revision upon the lines we have here indicated.

The tendency of the age is to make a boy a walking cyclopædia. Every faddist wants his hobby taught in the schools, forgetting that the boy has to live. Admitting that some science should be taught to boys, it should be that which will not have to be forgotten in the practical work of the world, but that which will be of assistance in such work. It may be that in some measure the following pages realise what is required, otherwise this book like hundreds of others had better be burnt by the common hangman, than put into the hands of the students

Glebe Lodge,
Champion Hill, s.e.

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ERRATA.

PAGE.

17. Fig 10. Earth connections shonld be shown at S and S_1, or these letters should be taken as representing ‘earth.’

18. For Fig. 18, read Fig. 11.

20. Line 10, $\frac{L}{R}$ should be $\frac{L}{S}$

22. Last line for ‘conductors’ read ‘conducting surfaces.’

78. Line 12-13 for ‘diminish the’ etc. read ‘set up a difference of pressure.’

167. Fig. 112, should either have two branches at top, or three in each of the other portions.

Electrical Engineering.

CHAPTER I.

INTRODUCTORY.

Electrical Engineer.—The Electrical Engineer can hardly be defined as belonging only to the class for which this book is specially written, for though many who are connected with the applications of electricity to telegraphy, telephony, electro-deposition, etc, may well be termed electrical engineers, it is not directly for them we write, but more especially for those engaged, or who propose to engage, in electric lighting and the electrical transmission of power. The application of electricity to telegraphy, telephony, etc., necessitates the dealing with minuter quantities and the making of far more delicate tests, than is the case with the other applications mentioned, wherein larger quantities are dealt with, and in which for all practical purposes the more delicate tests are not required. The work of the locomotive builder and the work of the watchmaker may both be classed as engineering, but the information required by the one is vastly different from that required by the other, and such is also the case in electrical engineering. Unfortunately for electric light engineers, the science of electricity as found in ordinary text books, has been developed with direct reference to telegraphy—the one great application at all common until quite recently. The units adopted and the nomenclature employed are telegraphic, hence not well adapted for use in the wider field they now have to fill. Still they exist, and the best use must be made of them that is possible.

Electricity.—What electricity is, we do not know. Certain phenomena connected with its actions have been studied, and certain laws deduced, which are of importance to the engineer and can be applied in his work to carry on the object he has in view.

Without entering to any great extent upon the various theories which have from time to time been put forward as explanatory of electrical phenomena, we may for the purposes of this book talk of electricity as an entity—a material which can undergo various modifications, and be so far controlled by the hands of man as to produce those phenomena we call electrical. The principal matters to be considered are:

How to produce the manifestation of electricity.
The path through which it acts.
Its measurement.

Electricity Constant in Quantity.—We shall assume that, whatever electricity is, it cannot be increased nor can it be decreased by any known means; in other words, the quantity of electricity in the universe is constant. Therefore, while it may be convenient sometimes to talk about the generation of electricity, it is certainly inaccurate, and only to be tolerated because it is almost impossible to be understood if common notions are rigidly avoided. So far as this book is concerned, its argument is that all the apparatus generally said to produce electricity, is really used to increase the activity of electricity. Just as we can get no flow of water without a difference of levels, so we can get no manifestation of electric or magnetic action without a difference of electrical level or pressure.

The apparatus constructed and employed, is for the purpose of producing this difference of pressure.

CHAPTER II.

THE CONDUCTIVE CIRCUIT.

The Circuit.—For many reasons it will be best to consider first the path, or, as it is usually called, the circuit through which electricity acts. Assume that we have an apparatus for the production of difference of electrical pressure; call it a source. In order to obtain electrical phenomena it is necessary to have a path along which the electricity may act. This path will generally be found to be a closed path or a number of closed paths, that is, paths which sooner or later return upon themselves. The path or circuit may be long or short, symetrical, or unsymetrical, but it seems essential that from whatever point it starts, to that point it must again return. Also, just as in ordinary walking the way may be smooth or rough, easy or difficult, so to electricity the circuit may be very easy or difficult. If electricity is left to choose its own path it ordinarily chooses the least difficult, or as it is called the path of least resistance. It is not necessary to have a battery as the source of pressure; it may be a frictional machine, or a dynamo, or a thermo-electric machine. For our purposes we can indicate this simple circuit thus:

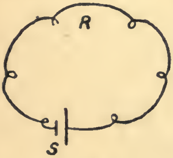


FIG. 1.

Where S, fig. 1, indicates the source, and R the wire or whatever materials form the circuit.

This part of the subject may be considered under these divisions:

1. The Conductive Circuit.
2. The Inductive Circuit.
3. The Magnetic Circuit.

The Conductive Circuit.—The materials that offer the least resistance to the flow of electricity—or as it is termed, to the current—are called conductors, while those that offer great resistance are called non-conductors, insulators. or dielectrics. Conductors are used to convey the electricity from point to point where it is wanted, and insulators to stop it from going where it is not wanted.

Most of the metals are conductors, some better than others; while gums, resins, glass, glazed ware, china ware, dry air, etc. are insulators. The following lists give some idea of the order of merit, so to speak, of conductors. The best conductors and the best insulators are placed at the top of the respective columns.

Conductors	*Insulators*
Metals	Paraffin
Gas Carbon	Shellac
Graphite	Ebonite
Acids	Amber
Aqueous Solutions	Resins
Vegetable Substances	Sulphur
Animal Substances	Glass
Soluble Salts	Dry Air and Gases
	Caoutchouc
	Mineral Oils

The best conductors present some obstacles to the current, and the best insulators are only those which present an enormously greater resistance to the passage of the current. So far as investigation has yet gone, we have neither perfect conductors nor perfect insulators; nor can a line be drawn to say when conduction ceases, and insulation begins. The difference between conductors and insulators is one of degree only.

The Simple Circuit.—Suppose we have a source S of electrical pressure, let it be the combination, fig. 2. of a glass jar three parts filled with dilute sulphuric acid (ten of water to one of acid), with strips of copper (Cu), and zinc (Zn), placed as shown in the dilute acid. So long as the combination remains as in fig. 2. there is no indication of a current. This circuit may be supposed to start from the surface Zn in the liquid, through the liquid to the surface Cu, and external to the liquid from Cu, through the air space to Zn. This would be a closed circuit, and is the circuit, but its resistance is far too great for the pressure that can be obtained by this combination to allow of a current. If, however, we decrease the resistance of the circuit by joining the external parts of the strips Cu, Zn, by a short copper wire W, fig. 3. electrical phenomena immediately present themselves. There is a current through the wire from Cu to Zn. Within the liquid the current is from Zn to Cu. The starting point of the current, or the point of production of pressure may for all practical purposes be supposed to be at the point of contact of the liquid and the zinc, for here is the point where chemical action takes place. The direction of the pressure seems towards Cu, so we trace the circuit from Zn through the

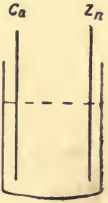


FIG. 2.

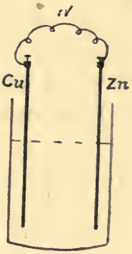


FIG. 3.

liquid to Cu, from Cu through the conductor W to Zn. In this apparatus, and in all apparatus with which we have to deal, a part of the resistance of the circuit is in the apparatus itself, generally called the *Internal* resistance; part is outside the apparatus and is called the *External* resistance.

Phenomena of the Circuit.—The phenomena connected with the circuit to be considered are four:

1. Resistance.
2. Current.
3. Pressure.
4. Leakage.

Resistance. The Ohm.—As all bodies offer greater or less resistance to the passage of a current, it is necessary for practical work to adopt a unit for purposes of comparison. At the present time the unit is called the **Ohm** and is *the resistance of a column of pure mercury 106 centimetres (41·73 inches) long, 1 square millimetre (·00155 square inches) in sectional area, at a temperature of 0°C.* However, just as the carpenter buys his two-foot rule, so the electrical engineer buys his sets of resistances. These indeed can be obtained arranged as required to assist in the process of measurement.

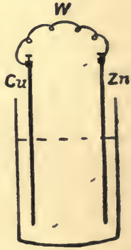


FIG. 3.

If in the experiment fig. 3 we change the short wire W for one much longer without altering its sectional area, we increase the resistance of the circuit, for we lengthen the path without making it easier. Indeed, we can go on thus increasing the length of the wire till the resistance is too great for the pressure, and the electrical phenomena then cease to be detected by our instruments. Similarly, by decreasing the sectional area without altering its length, we increase the resistance of the conductor. The pressure obtained from any given combination is always the same, and by noticing this we can adapt our combinations to the special purposes for which they are required.

The above definition is that of the unit termed the legal ohm, which however is scarcely or never used. The unit generally adopted in this country is called the B.A. unit, so named from having been made by a strong committee of the British Association.

1 B.A. unit = 0·9889 legal ohm.
1 legal ohm = 1·0112 B.A. unit.

It is improbable that for practical work the B.A. unit will ever be superseded. Many thousands of resistance coils had been made from the B.A. unit as a standard, at a great expense —and the expense would be very great indeed if these resistances had to be replaced. Besides nothing would be gained. The legal ohm is not the exact resistance of the true ohm, but the nearest whole number expressing the length of the metal of a particular sectional area, that has been used for the purposes of this definition. The stickler for scientific accuracy desires to know by how much the B.A. unit differs from the true ohm, and for his sake no doubt as instruments and methods become more perfect, corrections will from time to time be made in the third or fourth decimal place. No practical unit is absolutely perfect from the theorists point of view, but still we manage to weigh our tea and sugar, and measure the length of cloth and wood, and no great difficulty arises in the process either from the standpoint of buyer or seller.

Specific Resistance.—The metals are the best conductors, but the conducting power of each metal differs from that of other metals. Each has a resistance peculiar to itself, or a specific resistance. The resistance also changes with temperature, so that for practical purposes the choice of conductors must necessarily be restricted. The late Prof. Matthiessen investigated this subject and found that if we express the conducting power, or *conductivity* of hard drawn silver as 100· the most important metals come in the order below. Conductivity is the inverse of resistance, that is the *greater* the conductivity the *less* the resistance.

If Conductivity of pure *Silver* at freezing point be taken = 100·00.

then Conductivity	of pure	*Copper*	(hard)	=	99·9
,,	,,	*Gold*	(hard)	=	77·9
,,	,,	*Platinum*	(soft)	=	18·0
,,	,,	*Iron*	(soft)	=	16·8
,,	,,	*Tin*	(soft)	=	12·3
,,	,,	*Lead*		=	8·3
,,	,,	*Mercury*		=	1·6

The loss of conductivity and consequently the increase of resistance of these metals when raised to the temperature of boiling point is from 28 to 30 per cent.

Taking copper as the metal more largely used for conductors, the practical rule is that for every rise of temperature of 1° F, the resistances of the copper increases by ·002 per cent. A piece of copper therefore having a resistance of 1 ohm at 32° F would have a resistance of $1 + (\cdot 002 \times 50)$, or 1·1 ohm at 82° F, that is with a rise of temperature of 50° F, or a piece of copper with resistance 10 ohms at 32° F would have a resistance of 11 ohms at 82° F.

Ohm's Law.—In the early part of this century, Professor Ohm pointed out the relation between Current, Pressure and Resistance to be :

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

This is called Ohm's Law, and almost universally written

$$C = \frac{E}{R}$$

when C stands for Current ; E for Electrical pressure, or as usually termed Electro-motive-force ; and R for resistance.

Thus $C = \frac{E}{R}$, or $E = C\,R$, or $R = \frac{E}{C}$ gives the means of ascertaining the third quantity when the other two are known.

Practical units of current and pressure. Just as a practical unit of resistance has been adopted in the Ohm, so practical units have been adopted for current and pressure.

Unit of Resistance is called an	**Ohm.**
Unit of Pressure or Electromotive power	**Volt.**
Unit of Current	**Ampere.**

By Ohm's law $\mathbf{Amperes} = \frac{\mathbf{Volts}}{\mathbf{Ohms}}$

Examples—A few simple examples will show how these formulæ are used.

In fig. 1 if S represent the source of pressure in the circuit, and R the resistance. What would the current through W be if the resistance was 2 ohms and the pressure 100 volts ?

$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{100}{2} = 50$ Answer 50 Amperes.

What pressure is required to give 50 amperes through a resistance of 2 ohms?

$$\begin{aligned}\text{Pressure} &= \text{amperes} \times \text{ohms}\\ &= 50 \times 2\\ &= 100 \quad \text{Answer } 100 \text{ Volts.}\end{aligned}$$

What resistance is required to obtain a current of 50 amperes when the pressure is 100 volts?

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}} = \frac{100}{50} = 2. \quad \text{Answer } 2 \text{ Ohms.}$$

Divided Circuit.—In actual practice it is seldom that the circuit is of so simple a character. Thus if the simple circuit is represented by fig. 1 where S is the source and R the resistance, the circuit may be modified by introducing a second path, as in fig. 4. The current from S in Fig. 4 and 4a has the choice of path R_1 or R_2, or it may divide itself between both. It does the latter, and divides itself inversely as the resistances; that is, if the resistance of R_1 be double that of R_2 then twice the current will go through R_2 that goes through R_1. The greater the resistance the less the current, and the less the resistance the greater the current. It will be shown further on that the introduction of a branch circuit does not usually increase or decrease the current in the original circuit.

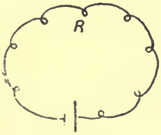


FIG. 1.

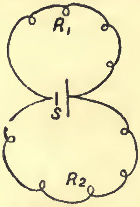


FIG. 4A.

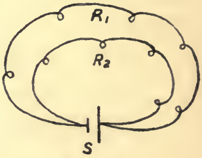


FIG. 4.

Suppose R has a resistance of 2 ohms, and R_1 a resistance of 1 ohm, then a current of 30 amperes would divide itself, and 20 amperes go in through R_1 while only 10 amperes went through R.

Generally if C is the current through R, and C_1 the current through R_1 then—

$$C \times R = C_1 \times R_1 \text{ or briefly } CR = C_1 R_1$$

$$\text{or } \frac{C}{R_1} = \frac{C_1}{R}$$

Any one of these quantities can be found when the other three are known, thus:

$$C = \frac{C_1 R_1}{R}; \; C_1 = \frac{C\,R}{R_1}; R = \frac{C_1 R_1}{C} \text{ and } R_1 = \frac{C\,R}{C_1}$$

If we put the figures given in the formula, we get

$$C \times R = C_1 \times R_1 \qquad \text{or } \frac{C}{R_1} = \frac{C_1}{R}$$

$$10 \times 2 = 20 \times 1 \qquad \frac{10}{1} = \frac{20}{2}$$

$$20 = 20. \qquad 10 = 10$$

$$C = \frac{C_1 R_1}{R} \qquad C_1 = \frac{C\,R}{R_1} \qquad R = \frac{C_1 R_1}{C} \qquad R_1 = \frac{C\,R}{C_1}$$

$$\frac{20 \times 1}{2} \qquad \frac{10 \times 2}{1} \qquad \frac{20 \times 1}{10} \qquad \frac{10 \times 2}{20}$$

$$= 10 \qquad = 20 \qquad = 2 \qquad = 1$$

Shunts.—In the case of the double paths or circuits just described, the one is said to be a shunt, a parallel, or a branch circuit to the other, and it will be seen that it is only necessary to adjust the resistances, to have any given part of the total current through one branch and the remaining portion through the other.

With a current of 50 amperes it is required that 40 amperes go through one branch and 10 through another: what must be their respective resistances? By dividing the number indicating the larger of the two split currents by the smaller, *i.e.* $\frac{40}{10} = 4$ we get a number indicating how many times the resistance for the smaller current must be greater than that for the larger. In this case if the smaller resistance for the larger current is 1 ohm, the larger resistance for the smaller current must be 4 ohms.

When the circuit has two branches, and has to be wound round a piece or pieces of iron on its way, there are two ways of so winding. Suppose for example, it has to go round the two rods A and B, we can wind only one branch round as shown in fig. 5 or both branches, as shown in fig. 6.

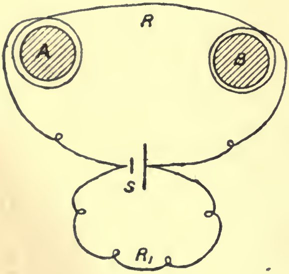


FIG. 5.

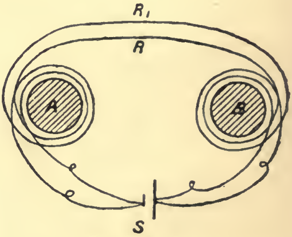


FIG. 6.

A dynamo wound as in fig. 5 is called a shunt dynamo, while one wound as in fig. 6 is a componnd wound dynamo. Of course anything similarly wound, is shunt or compound wound respectively.

It stands to reason that if you have a circuit as shown in fig. 1, and then add another path for the current as in fig. 4 you decrease the resistance of the circuit, and unless due precaution is taken the total current is thereby increased.

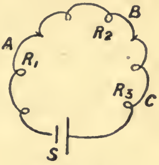


FIG. 7A.

Total Resistance. If resistances are arranged one after another as in fig. 7 and 7a. they are said to be in series.

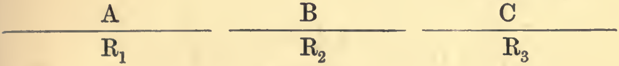


FIG. 7.

If the resistance $A = R_1$; if $B = R_2$; and if $C = R_3$ The total resistance of $A + B + C$ is the sum of the separate resistances. Let R = the total resistance. Then

$$R = R_1 + R_2 + R_3$$

If, however, the resistances are arranged in shunt or in multiple arc, as in fig. 4 and fig. 4a the total resistance is not the sum of the separate resistances.

Let the resistances arranged as shunts, with their extremities in contact with the same two points A and B, have respectively the resistances R_1 and R_2. Let the difference of electrical pressure betweenA and B = E

$$\text{then current } C_1 \text{ through } R_1 = \frac{E}{R_1}$$

$$\text{and current } C_2 \text{ through } R_2 = \frac{E}{R_2}$$

the total current C is the sum of the separate currents

$$C = \frac{E}{R_1} + \frac{E}{R_2}$$

If the difference of pressure of $E = 1$,

this current becomes $\frac{1}{R_1} + \frac{1}{R} = \frac{R_1 + R_2}{R_1 R_2}$

but current is inversely as resistance, hence

total resistance $R = \frac{R_1 R_2}{R_1 + R_2}$

With three conductors, having respectively resistance R_1 R_2 R_3. total current =

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_2 R_3 + R_1 R_3 + R_1 R_2}{R_1 R_2 R_3}$$

$$\text{And} \quad R = \frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}$$

If there are such N resistances, then the total resistance =

$$\frac{\text{Product of N resistances}}{\text{Sum of products of resistances taken (N—1) together.}}$$

EXAMPLES.—Find the joint (total) resistance of two conductors having respectively 4 and 6 ohms resistance?

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{4 \times 6}{4 + 6} = \frac{24}{10} = 2{\cdot}4 \text{ ohms.}$$

Find joint resistance of multiple arc of three conductors having respectively resistances of 4, 6 and 8 ohms?

$$\frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2} = \frac{4 \times 6 \times 8}{(6 \times 8) + (4 \times 8) + (4 \times 6)} = \frac{192}{104}$$
$$= 1{\cdot}846 \text{ Ohms.}$$

If the several resistances found in multiple arc, are similar and have the same individual resistances the total resistance is

$$\frac{\text{Resistance of one branch}}{\text{Number of branches.}} = \frac{R}{n}$$

Thus. Take two branches, each having a resistance of 5 ohms, according to the formula.

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{5 \times 5}{5 + 5} = \frac{25}{10} = 2{\cdot}5 \text{ ohms.}$$

$$\text{Or} \quad \frac{\text{Resistance one branch}}{\text{Number of branches}} = \frac{5}{2} = 2{\cdot}5 \text{ ohms.}$$

Again with three branches, each having 5 ohms resistance

$$R = \frac{R_1 R_2 R_3}{R_1R_3 + R_1R_3 + R_1R_2} = \frac{5 \times 5 \times 5}{(5 \times 5) + (5 \times 5) + (5 \times 5)} =$$

$$\frac{125}{75} = 1\tfrac{2}{3} \text{ ohms.}$$

$$\text{Or} \quad \frac{\text{Resistance of one branch}}{\text{Number of branches}} = \frac{5}{3} = 1\tfrac{2}{3} \text{ Ohms.}$$

Shunts to be avoided.—The extended use of currents with high electromotive force necessitates greater care in the manipulation of the apparatus used. It is not difficult to place the body so that it acts as a shunt to the earth. It must be recollected that both body and earth are conductors, and that with the currents used in electric light work there is always more or less danger to life if they are passed through the body. The minimum current or pressure that is dangerous is unknown. The resistance of the body is not constant, so that what is safe at one time may not be safe at another. Further the resistance of the body together with the other parts of the circuit in which it happens to be is unknown Thus while it might be safe to stand in dry shoes upon dry ground, it may be unsafe if the shoes were damp and the ground damp, or dry shoes upon damp ground might be unsafe. The best plan then is to avoid placing the body in the direct circuit or in a shunt circuit. It is often thought that touching a wire with one hand is a safe proceeding, but this is not so, the action may either put the body in the direct circuit or in a shunt curcuit. Thus in fig. 8 let S be the source and RR_1 a broken wire with the end G fallen on the ground or to a conductor C leading to the ground. If the end S_1 is also connected through a conductor C_1 to the ground, the circuit is completed through the earth as shown by dotted lines. If C_1 happens to be a man's body the body becomes a part of the circuit and the result may be fatal. Again, let S, fig. 9 be the source, P and P_1 the terminals

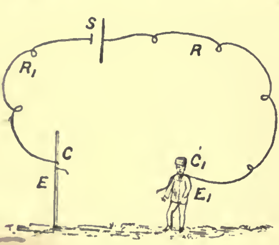


FIG. 8.

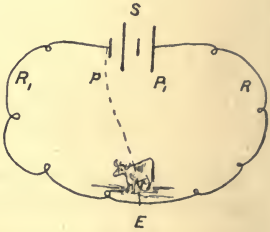


FIG. 9.

of the source, one of which, say P, is somehow or other not insulated thoroughly from the ground. So long as the only circuit is the wire circuit RR_1, no part of which is connected through a conductor to the ground, there is no danger; but suppose a man standing on the ground takes hold of RR_1, at E a shunt circuit is formed through the body and the ground as shewn by the dotted lines, and the body gets a current. Two lessons should be thoroughly learnt from this. First, to lessen danger to life all dynamo machines should be well insulated from earth, and secondly, when working among currents approaching danger the greatest care should be taken not to put the body into a direct or into a shunt circuit. Another case ought to be illustrated for it is perhaps more often fatal than any other, it is that of forming a bridge between two circuits. Thus in fig. 10 let S and S_1 be two sources. Say S is the source of an electric light circuit, S_1 of a telephone or telegraph circuit. The difference of electric pressure between any point P in the electric light circuit, and any point P_1 in the telephone circuit will be great, and therefore a current would go through a conducting body joining P and P_1.

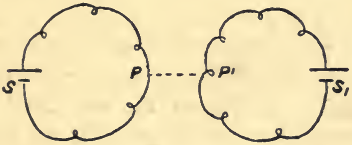


FIG. 10.

THE INDUCTIVE CIRCUIT.

Inductive or Conductive.—It is customary to view the inductive circuit as something altogether different from the conductive, whereas the one is in reality but a modification of the other. The modification introduces more prominently certain phenomena which are important and have now to be considered. Induction is a term used to denote a condition which in different circumstances seems altogether distinct from what it does under other circumstances, yet a closer examination will show the similarity. There can be no flow of current without difference of electrical pressure, but there can be difference of electrical pressure without current. The former case, difference of pressure with current, exists in the conductive circuit; the latter case, difference of pressure but no current, exists in the inductive circuit. We have said electrical apparatus is used for producing electrical pressure. It will bring the idea more into harmony with existing notions and perhaps be of greater assistance to those who have imbibed existing notions, if we look upon the apparatus as having a double object, raising pressure on the one side and proportionately decreasing it on the other. Thus we get two conditions the counterpart of each other, a quantity of electricity on the one hand under more electrical pressure, an equal quantity on the other side under less electrical pressure. The lifelong object of electricity in these different states is to get together and resume the normal condition, or the condition of normal pressure when electrical phenomena are indicated.

We can now represent the simple inductive circuit. Suppose a source S of electrical pressure, and conductors A and B separated by the air space D. fig 11. Suppose further the pressure to be increased in direction of A, and diminished in direction of B, then when contact is made with the source we get a momentary rush or current in direction A, and as it were a slight heaping up of the electricity in A and a corresponding diminution in B. This heaping up, or accumulation, as it is called, takes place principally upon the surface of A immediately opposite to B, or the electricity in unlike conditions of pressure gets as near together as possible.

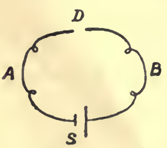


Fig. 11.

The quantity so accumulated at the ends of wires is extremely small, but it is easy to arrange the circuit so that quantities measurable by our instruments can be dealt with.

Electrical Conditions.—First, however, it may be wise to point out that these two electrical conditions are fully recognised. In early days they were called vitreous and resinous, and were thought to be two different electricities, later on one kind of electricity was recognised, and the states were thought to indicate an extra quantity in the one case and a diminished quantity in the other, later still the conditions were simply termed positive and negative, and represented by + and −. The later terms suit our purpose, hence we shall speak of electricity under the greater pressure as positive +, and electricity under less pressure as negative −.

Simple Inductive Circuit.—A simple inductive circuit may be arranged as in fig. 12. Let S be the source of electrical pressure, A and B wires joining the terminals of the source with the parallel conducting surfaces or plates shown in section P, P_1 at a distance from other conductors. The air space between P and P_1 forms the

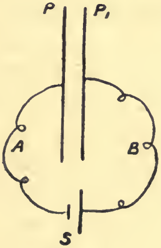


Fig. 12.

dielectric, nonconductor, or inductive resistance. If the distance between P and P_1 be taken as the length of the resistance, and the surface area of the opposing surface of one of the plates as the sectional area of the resistance, then just as in the conductive circuit the resistance varies directly as the length of the conductor and inversely as its sectional area, so in the inductive circuit the resistance varies directly as the length and inversely as the sectional area of the dielectric. In other words, if you double or treble the length of the dielectric, you double or treble its resistance, while if you double its sectional area you halve its resistance. This is symbolised by $R \propto \frac{L}{KS}$ when R = resistance of dielectric, L its length, and S its sectional area. In both circuits then we have similarly the source of electrical pressure, and resistance of circuit. The result of electrical pressure in the conductive circuit is current, in the inductive circuit it *seems* to be accumulation on the surfaces of the opposite conductors. We say *seems* because the probable action is at the surface of the dielectric in contact with the conductors and not on the conductors. In this case, however, the use of the popular expression will do no harm.

The idea of accumulation involves that of density per unit area, and if the plates are throughout their surfaces at the same distance apart the same source accumulates or charges them all over the opposite surfaces to the same density. The quantity accumulated, or the total charge, will evidently be the density per unit area × by number of units of surface. It will now be seen that accumulation in the inductive circuit is analogous to current in the conductive circuit, and that the same laws apply to both.

Current × Resistance = Electrical Pressure ; or $C \times R = E$

Accumulation × Resistance = Electrical Pressure;
Or A × R = E

Inductive Resistance—Series—Multiple Arc. Inductive resistances are added in series just as conductive resistances. Thus figs. 13, 14, show two resistances in series; figs. 15, 16, show three resistances in series. In either case the length of dielectric has either been doubled or trebled and the total resistance

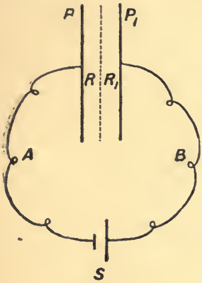


Fig. 13.

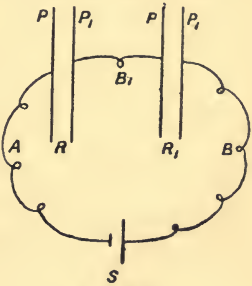


Fig. 14.

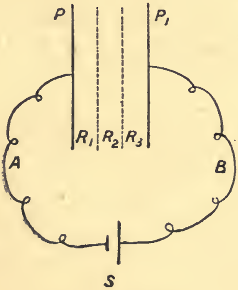


Fig. 15.

in the first case $R = R_1 + R_2$
Or in the second case $R = R_1 + R_2 + R_3$.
If $R_1 = R_2 = R_3$ etc., then $R = nR_1$.

In the conductive circuit the practical effect, as far as total resistance is concerned, of adding conductors in multiple arc is the same as if the sectional area of the conductor is increased, thus the resistance of the circuit R fig. 17 would be halved either by adding another similar conductor, or doubling the sectional area of R. Similarly, in the inductive circuit the practical effect of the addition of resistances in multiple arc is to increase the sectional area, and correspondingly to decrease the resistance. Thus if in fig. 18, P and P_1 be the opposing ~~conductors~~ and R

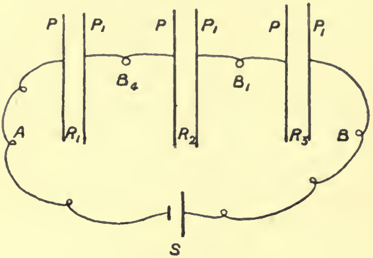


FIG. 16.

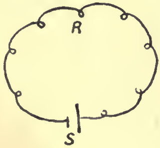


FIG. 17.

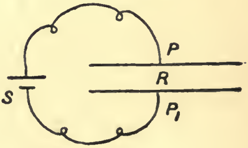


FIG. 18.

Conducting surfaces.

the inductive resistance, and if P and P_1 be increased to double size, as shown by the dotted lines in fig. 19, or a similar resistance be added as shown in fig. 20, the total

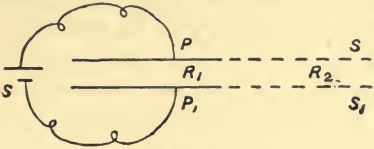


FIG. 19.

resistance R will be $R = \frac{R_1 R_2}{R_1 + R_2}$ as in the conductive circuit, for let the respective resistances be R_1 and R_2,

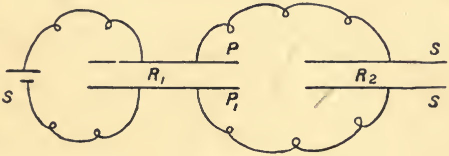


FIG. 20.

and the pressure be unit pressure between the surfaces, and let the joint or total resistance be R, thus:

$$\text{accumulation on P or } P_1 = \frac{1}{R_1}$$

$$\text{,, \quad ,, S or } S_1 = \frac{1}{R_2}$$

Total accumulation on P and S, or P_1 and $S_1 = \frac{1}{R_1} + \frac{1}{R_2}$

$$= \frac{R_1 + R_2}{R_1\, R_2}$$

but as accumulation is inversely as resistance $R = \frac{R_1\, R_2}{R_1 + R_2}$

Distribution of Charge. It has been stated that in the conductive circuit the current distributes itself inversely as the resistances; so in the inductive circuit the charge or accumulation distributes itself inversely as the resistances. Thus in figs. 19, 20, the addition of plates S S_1 equal to P or P_1, with $R_2 = R_1$, pressure remaining constant, leads simply to doubling the charge because the resistance is halved, the quantity and density on P or P_1 being equal to quantity and density on S or S_1. If, however, R_2 is different from R_1 as in fig. 21, the total accumulation will be increased because the total resistance is lessened. A little consideration will show that the quantity accumulated always so varies. Suppose for example R_2 is twice R_1 we may represent

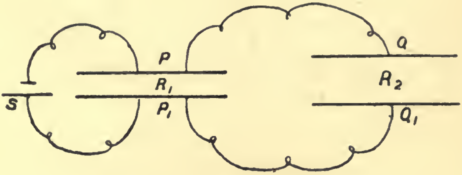


Fig. 21.

$$R_1 = 1 \text{ and } R_2 = 2$$

$$\text{Total Resistance R} = \frac{R_1 R_2}{R_1 + R_2} = \frac{2}{3}$$

that is the resistance of the original circuit $R_1 = 1$ is now by the addition of R_2 reduced to $\frac{2}{3}$ and the charge will therefore be correspondingly increased. And if 10 represents the old quantity accumulated and x the new quantity.

$$\frac{\text{New resistance}}{\text{Old resistance}} = \frac{\text{Old charge}}{\text{New charge}}$$

$$\frac{\frac{2}{3}}{1} = \frac{10}{x}$$

$$\frac{2}{3}x = 10 \text{ whence } x = 15$$

In symbols, if Q = old quantity, and Q_1, new quantity, accumulated

$$\frac{R_1 R_2}{R_1 + R_2} : R_1 :: Q : Q_1$$

This new charge is distributed inversely as the resistance, that is, 10 parts, with resistance R_1, and 5 parts with resistance R_2. It will be seen that no change has taken place as regards the charge on P or P_1, and this will be found to hold good whatever branch resistance may be added to the circuit. Similarly, in the conductive circuit the adding of parallel, branch or shunt circuits, with pressure remaining constant does not affect the current through the original circuit.

Short Circuits.—When the resistance of the conductive or of the inductive circuit is decreased to a small quantity, the current or the accumulation is enormous. An examination of the formulæ will show that any amount of current or accumulation can be had with any pressure, however small. Anyone who understands division in arithmetic will easily understand our meaning. Thus, suppose we have to divide any number, say 5, by any number greater than unity, the answer will be less than 5, it is exactly 5 when we divide by unity, but when we get on the other side of unity and divide by numbers less than unity the answer is greater than 5.

Take these examples

$$5 \div 2 \text{ or } \frac{5}{2} = 2\tfrac{1}{2}$$

$$5 \div 1 \text{ or } \frac{5}{1} = 5$$

$$5 \div \tfrac{1}{2} \text{ or } \frac{5}{\cdot 5} = 10$$

$$5 \div \tfrac{1}{4} \text{ or } \frac{5}{\cdot 25} = 20$$

Thus in $C = \frac{E}{R}$ or $A = \frac{E}{R}$ whatever pressure E may indicate the current C or accumulation A may be as great as we please provided we make R in each case small enough.

It is this short circuit in practical work that leads, as we have before seen, to great danger. Whether the original circuit be conductive or inductive the result of a short circuit is the same—the passage of a large current through a small resistance.

Specific Inductive Resistance.—Faraday found that by substituting another gas for air as the dielectric the resultant charge was unaltered—and he also found for all the solid and liquid dielectrics he experimented with a greater capacity for accumulation than with gases. He thus introduced the term 'specific capacity.' It would seem preferable now to look upon all gases as having the same resistance, and solids and liquids as having different resistances. If the resistance of unit length and unit sectional area of air be taken as the unit then the resistance of other insulators compared with this might be termed their specific inductive resistance.

THE MAGNETIC CIRCUIT.

Magnets. Four kinds of magnets may be met with, two kinds only however are found in practical work. The natural magnet natural oxide of iron having the chemical composition $Fe_3 O_4$ is found in various iron mines, in Sweden, Spain and other parts of the world. This kind of magnet is of no interest to the practical man being too weak and too cumbrous to be of any service. Yet by the aid of the natural magnet the first artificial magnet was probably obtained but who first noticed the effect of a magnet upon iron and steel is not known. Artificial magnets are of three kinds. That best known is obtained by rubbing steel with a natural, or another artificial magnet, or by magnetising the steel by inserting it into an hollow coil of wire, and then passing an electric current through the wire. The magnets so obtained with hard steel are called permanent magnets for they retain the magnetic properties imparted to them. The strongest and most useful magnets for engineering work are temporary magnets made by wrapping a coil of insulated copper wire round a core of soft iron, or core of soft iron wire. Upon sending an electric current through the coil the core is temporarily magnetised; in fact it is magnetised just as long as the current is kept up. The core seldom loses the whole of its magnetism when the current is stopped except it be the very best and purest soft iron. The small amount of magnetism retained is called residual magnetism. Such temporary magnets are called electro-magnets. The other kind consists of a coil of wire only, without a metallic core, and when a current is sent through such a coil, the coil acts as a magnet.

Phenomena of a Magnet.—One of the peculiarities that distinguish magnets from other bodies is that if free to take up that position they will come to rest in a position pointing almost due North and South, hence the end of the magnet which turns to the North has been called the North seeking or simply the North pole of the magnet while that which points South has been similarly called the South pole. This property makes the magnet or the compass of the greatest value in navigation. Again if a piece of iron smaller than the magnet be brought near it, the magnet seems to attract the iron towards itself—and if the iron be near enough and small enough it will be drawn into contact with the magnet. Further a magnet is capable of so acting upon another magnetic body as to make that body a magnet. Thus if we take a small bar of steel A B Fig. 22, and a bar magnet M place the magnet M upon one end of A B at right angles to it, and draw it along from A to B then lift up M some distance from B and carry it through the air still away from A B, bringing the same pole say N gently down on A again. Repeat this several times on each of the surfaces of A B, the pole of the magnet being always passed in the same direction. It will be found that A B, is a magnet, the end where contact was first made with N being a North pole like N and the end where it leaves being a South Pole. There are several other ways of making magnets, this is only mentioned to show the property existing in the magnet.

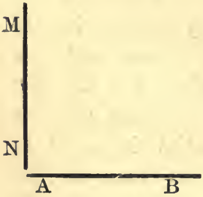


Fig. 22.

The last peculiar feature of a magnet to be mentioned is if a magnet is broken into two, four or any number of similar pieces, we get two, four, or whatever the number may be of complete magnets. Thus if a bar magnet, be divided into two equal parts we get the two similar bars which will be found to be perfect magnets.

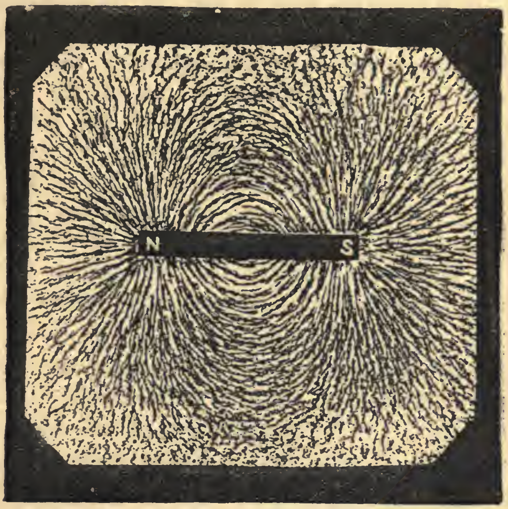


Fig. 23.

If we divided these smaller bars again and again, we should find each piece a perfect magnet, and from this it is inferred that the act of magnetism causes the molecules of the iron to arrange themselves in a particular order, gives them in fact polarity. As an aid to understand this phenomenon the immortal Farady introduced the conception of lines of force as issuing from the north pole of a magnet and polarising or arranging complete molecular chains to the south pole. The action of lines of force upon iron filings can easily be seen. Let N.S. Fig 23, represent a magnet. Upon this lay a sheet of paper and sprinkle iron filings upon the paper. The filings will arrange themselves after the manner shown in the figure. Gently tapping the paper will aid in getting better curves. If we look upon the lines of force as lines of polarised molecules, and if we look at a polarised molcule as having as its sole object the polarisation of the molecule next to it in the direction of the easiest path for making a complete chain, many of the phenomena of magnetism can by this assumption be easily explained. Be it understood there is no intention of propounding this as a theory of magnetism, all that is aimed at is to explain by some simple mechanical or illustrative method the phenomena that the practical man has to harness and utilise in his work.

Returning for a moment to the conductive circuit, as represented in FIG. 24, we have hitherto said nothing of the electrical phenomena occuring in the spaces adjacent to that circuit, but the consideration of these phenomena is as important as the consideration of pressure, current and resistance. If a current is passing along the wire R R. it exerts an influence in the space immediately surrounding the iron. This influence is greatest close to the wire and gets gradually less and less farther away. The space over which such influence is exerted is called the "field." A simple experiment will show this influence exists and at the same time tells us a

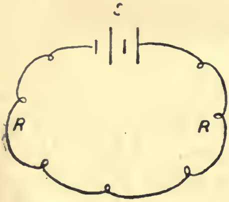


FIG. 24.

little about its action. Suppose Fig. 25, to represent a portion of wire forming part of a conductive circuit through which a current is passing. If we take a sheet of paper or glass, and lightly sprinkle iron filings upon the plate of glass we shall find that the

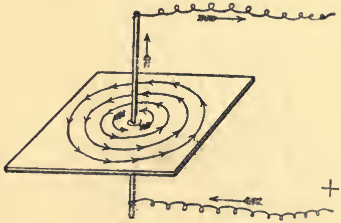


Fig. 25

filings will arrange themselves somewhat concentrically around the wire, that is we find some force acting upon the filings, causing them to assume the ring shape. We may say that the position of each ring of filings is determined by a force acting in a certain direction, or forces acting in certain directions. It is clear that the force or forces start somehow from the conductor, hence we not inaptly speak of lines of force, and of the total space through which the lines of force act as the "field of force". It must be remembered however that we use the term lines of force only as a convenience.

Suppose the wire forms a loop or coil in a circuit, the same phenomena of the lines of force occur, and these lines as it were thread the coil. Further increase the number of turns of wire the lines of force still thread the coils as in

Fig 26. Coils like these act exactly as do ordinary magnets. The number of lines of force are in the simple conditions proportional to the currents. We have hitherto referred to the lines of force traversing air space, but if we substitute for the air some material that offers a less resistance to the passage of these lines of force, such as soft iron, the number of lines of force through unit surface will be increased. Thus we obtain the ordinary Electro Magnet which consists of a core of soft iron, around which is wound insulated copper wire. The lines of force all pass through the core and may be supposed to leave the core at the North Pole and enter at the South Pole.

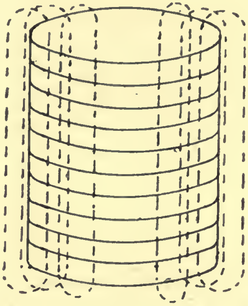


FIG. 26.

Magnetic Circuit.—The longer the air space to be traversed by the lines of force the greater the resistance, so for most practical purposes the iron or steel part of the circuit is bent so as to bring the ends or poles as near together as possible and reduce the air space to be traversed by the lines of force. Fig 27, shows the ordinary form of magnet. If the iron or steel forms a complete ring as Fig 28, then all the lines of force traverse the ring and we get *no* external effect. In practice we require external effect, in other words we want lines of force traversing air or some body similar to air so that we can bring other conductors into and take them out of the field of force, or move them to various positions within the field, hence the core of our magnets does not form a complete ring but leaves an air space as in Fig 29.

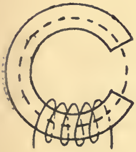


FIG. 29.

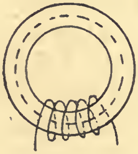


FIG. 28.

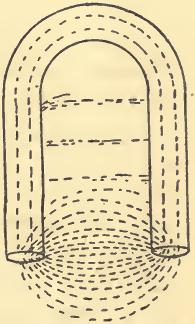


FIG. 27.

The longer the air space the greater the resistance of the magnetic circuit, for the air space constitutes the greater part of the resistance of the circuit, so in designing magnets for practical work great care should be taken to have the poles as close together as the nature of the work permits. When the direct resistance between the poles is great, lines of force are apt to find their way across other points of the magnet arms as indicated in fig 27. These leakage lines are waste lines and therefore to be avoided.

In the magnetic circuit we may take the "number of lines of force" to be analogous to "current" in the conductive, or "accumulation" in the inductive circuit; and ohm's law applies to this circuit as to the others. Thus

$$\text{No. lines of force} = \frac{\text{Pressure due to current in coils of Magnet.}}{\text{Resistance.}}$$

The similarity of the law regulating the conductive, inductive, and magnetic circuits can easily be seen.

Thus in the Conductive Circuit $E = R \times C$
Inductive ,, $E = R \times A$
Magnetic ,, $E = R \times L$

When E = pressure ; R = resistance, C = current ; A = accumulation and L = No. of lines of Force.

In an elementary book of this kind it is impossible to enter fully into any one portion of this vast subject, but it will be seen that looking upon "circuits" as necessary parts of the phenomena; the peculiarity of always having in every circuit that can be examined two points, usually called poles, exhibiting phenomena just the opposite of each other is easily understood. Thus a perfect magnet like a ring of iron has no observable poles. When however we break the ring we have lines of force leaving one pole and entering the other.

Magnetic Conductors.—Only three substances have been found which possess the property of being magnetisible to any extent, though probably this phenomenon is similar to conductors and insulators in the conductive circuit, and with greater and greater magnetic pressure more and more substances will show magnetic phenomena. But at any rate the ordinary magnetic substances are iron, nickel and cobalt, and of these iron is far and away the best. Just however as impurities such as arsenic in copper greatly reduce its value as a conductor, so impurities in iron reduce its magnetic properties. A little manganese alloyed with the iron makes an alloy almost non-magnetic.

THE INTERACTION OF CIRCUITS.

Interaction.—By the interaction of circuits is meant the phenomena which occur upon bringing circuits within the sphere of influence of each other. There are six ways in which two circuits can interact, when there are three kinds of circuits, for each can be brought within the influence of one similar to itself, or one of the other two. But to the phenomena attending these interactions, must be added those attending the actions of circuits upon neutral bodies. Then we can have the

Conductive circuit within the influence of a Conductive circuit
,, ,, ,, ,, ,, ,, an Inductive ,,
,, ,, ,, ,, ,, ,, a Magnetic ,,
Inductive ,, ,, ,, ,, ,, an Inductive ,,
,, ,, ,, ,, ,, ,, a Magnetic ,,
Magnetic ,, ,, ,, ,, ,, a Magnetic ,,

and three others namely the action between each of these three and a neutral circuit.

In considering a conductive circuit a double set of observations must be made, one concerning the phenomena inside the conductor, one concerning those outside. The latter are perhaps the most important at this part of the subject. The current in a conductor seems to act in a direction parallel with the direction of the axis of the conductor, while the direction of the external action or influence seems to be at right angles to the axis.

Let A B Fig 30, represent a part of a conductor carrying a current. The direction of the current is parallel to the axis AB. The external phenomena are those due to an inductive circuit or circuits, and the field or space over which the influence extends is simply the dielectric space between the conductors bounding the inductive circuit. It has become customary to describe all phenomena taking place in this field, also in the magnetic field as due to induction. It is very convenient although not very exact to do this, but the real action is the bringing of something not previously in the field or circuit, into it, and making a new link in the circuit. The meaning can be better explained from examples. Thus let R.R. Fig 31, represent a conductive circuit, consisting of a source and copper wire R.R. Let C be another piece of

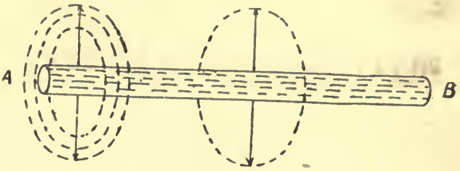


FIG. 30.

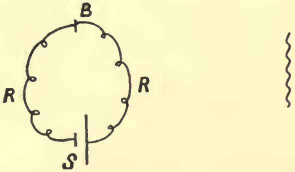


FIG. 31.

copper wire similar to R not in the circuit nor within the influence of the field. None of the phenomena appearing in R will be expected in C but if R be broken and C inserted as in Fig 32, C becomes a part of the conductive circuit and no one is surprised to find it carrying current and producing a field.

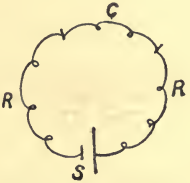


Fig. 32.

Again let $P.P_1$ Fig 33, represent the opposing conductors of an inductive circuit separated by air, and Q a conductor similar to P or P_1, but not in the circuit. No inductive phenomena is shown by Q but if Q be brought into the position Q_1 Fig 34, between P and P_1 it forms a part of the circuit and accumulation takes place, the distribution being as shown in the diagram.

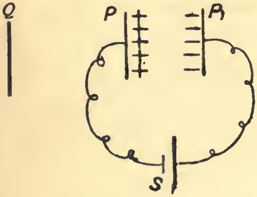


Fig. 33.

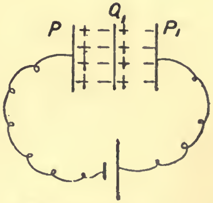


Fig. 34.

Further let N S fig 35, represent a magnetic circuit and let there be a piece of iron outside the circuit. No influence is exerted on this iron, but on bringing it into the field as in fig 36, the resistance of that part of the field is immediately reduced, the lines of force going through the iron and rendering it magnetic. These and similar considerations will assist in explaining the action of circuits upon neutral bodies. Besides the action upon the foreign body brought into the circuit, the conditions of the circuit itself are altered and changes may be noted. Thus the bringing in of C. fig 32, increases the resistance of the circuit, and correspondingly decreases the current if the pressure remains the same. Similarly the introduction of Q. fig 34, decreases the inductive resistances and correspondingly increases the accumulation the pressure being constant. If instead of inserting the conductor Q

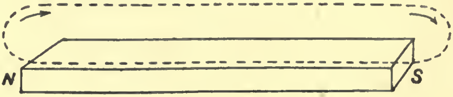


Fig. 35.

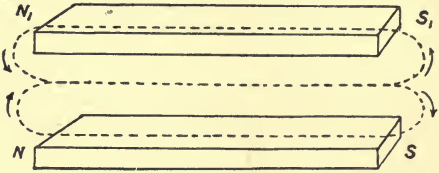


Fig. 36.

into the circuit, the dielectric had been changed for another dielectric of different specific resistance there would have been a corresponding change in the accumulation. This seems to be a simpler way of looking at the various phenomena than to attempt to explain them by means of intricate mathematical formulæ. A body which is not in the circuit can therefore show none of the phenomena of the circuit.

Assuming that the magnetic field is due to lines of polarised molecules, each line of polarised molecules forming a closed circuit, we have to consider what happens when lines of polarised molecules are brought into contract with other similar lines, either in the magnetic or in the inductive circuit. In the first place, and it is a most important fact, no two lines can occupy the same space, therefore if any attempt is made to force one lot of lines among another lot, there will be disturbance and distortion of field of some kind.

Suppose we bring a magnet with lines of force into proximity to a conductor carrying a current. Let the magnet be parallel to the axis of the conductor, by this means, we forcibly disturb the lines of polarisation both of the magnet and of the conductor, and in the disturbed part the force due to the conductor tends to make the molecules under its influence take up a position at right angles to the molecules under the influence of the magnet. In fact we have two sets of forces acting at right angles—the result being that under these forces either the conductor or the magnet moves, till the forces are acting in the same direction. Usually the magnet and the magnetic force is small in comparison than that of the conductor, and therefore the tendency is for the magnet to place itself at right angle, to the axis of the conductor as in this position the polarising forces are parallel or in the same direction. Our meaning will be clearer by an examination of Fig 37.

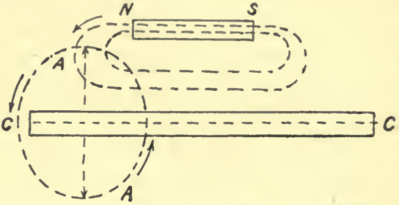


Fig 37.

In Fig 37, C. C. represents the conductor—a chain of polarised molecules due to which is shown by the circle A while N.S. represents the magnet with polarised molecules. The arrows represent the direction of the force causing polarition in each case. In Fig 37 two such polarised molecules come into contact at A—and the aim of these molecules is to get into the position due to the force of polarisation due to the current, that being stronger than the force of polarisation due to the magnet. If, however, the magnet is powerful compared to the conductor, then the conductor will move, the polarised molecules of both conductor and magnet having finally the direction due to the magnet force.

Thus the tendency of a magnet and a conductor when brought into juxtaposition is to place their axes at right angles to one another.

We have already seen that the action of a current in a coil upon a core of iron or steel is to render the core magnetic, the one temporarily, the other permanently. Reversing the current in the coil will reverse the polarity of the temporary or permanent magnet, so a permanent magnet can be demagnetised and remagnetised in the opposite direction by inserting it into a coil carrying a current. The apparatus of a coil carrying current and magnetising a core is reversible, for if we have a coil not carrying a current and insert a magnet into that coil a temporary current is set up in the coil, the direction of which depends upon whether the N or the S pole in the magnet is first inserted. When the magnet is withdrawn, a similar temporary current but opposite in direction to that at insertion takes place, also if a conductor is brought from outside into any part of a magnetic field a current is temporarily set up in that conductor.

A little more attention may be given to this. The field due to a current, as we have seen, causes iron filings to assume the position of closed rings round the conductor. Every field is proportionate to the strength of the current, thus we may say every current gives a definite number of lines of force. It is important to know if the reverse of this is the case, and to know if a definite number of closed lines of force will give a definite current. The magnetic field consists of a number of loops of polarised molecules forming a number of closed circuits. Let N S Fig 38, be a

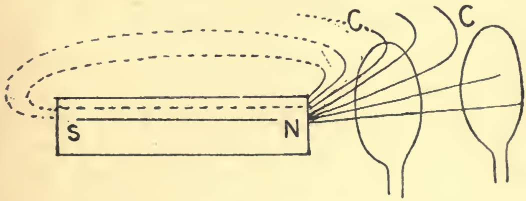


Fig. 38.

magnet with the field as shown. If a conductive circuit C is brought into the field, a certain number of loops or lines of force thread the conductor, and these set up a definite temporary current in the conductor. If the number of loops of force which thread the conductor is doubled, then the temporary current set up is also doubled. The current is proportional to the number of loops, so that moving the conductor from position C to position C_1 so as to be embraced by more loops, will increase the current. Of course the number of closed loops is exactly the same as the number of lines going through the conductive circuit, and so it is customary to say the current is proportional to the number of lines of force which pass through the circuit. We have seen that a single loop of conductor possesses all the properties of a magnet, and as any conductive circuit is a closed circuit, it is needless to say it is magnetic, therefore if any conductor be brought into the conductive field, a current will be temporarily set up in the conductor so brought into the field. We have seen, it depends upon the direction of the current in the coil for the reversal of the magnetic circuit, so it depends upon the direction of the current if any in a conductor brought into a conductive field whether the action of the field upon the conductor tends to decrease or to increase that current. It may at once be said that if a neutral conductor is brought into a conductive field, the current induced is opposite in sign to that of the conductor carrying the current, so if a conductor carrying a current be brought into the field of another conductor carrying a current of opposite sign, the current will be increased; if of the same sign, it will be diminished. We may now summarise the interactions.

A conductor brought within the influence of a conductive circuit has induced in it a temporary current opposite in sign to that of the conductor carrying the current, but on being taken out of the circuit has a temporary equal current of the same sign. Thus if AB Fig 39, is a conductor called a primary conductor carrying a current in the direction shown by the arrow, and a conductor CD a secondary conductor is *brought into* its field, a temporary current is set up in CD but in the direction shown by the arrow.

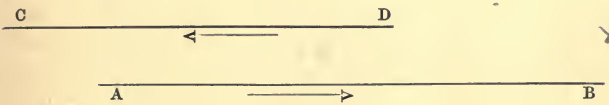


FIG. 39.

On taking CD out of the field of AB, a current is set up similar to that when brought in, but opposite in direction to the original current set up in CD and is now in the same direction as that in AB Fig 40.

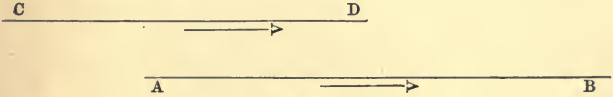


FIG. 40.

If the conductor CD is carrying a current and is brought within the field of AB, then if the currents are in the same direction there will be a temporary decrease in the current in CD, and on taking it out of the field can equal temporary in increase.

Similarly if a conductor is brought into the field of a magnet a temporary current is set up in the conductor in one direction, and when the conductor is taken out of the field an equal current is temporarily set up in the opposite direction.

Attraction and Repulsion.—It is convenient for the mathematicians to accept the phenomena called attraction and repulsion, but as far as experiment is concerned there is no proof of the existence of any such property as repulsion. If we attempt to put a second barrel of water into a barrel that is full already there is no repulsion in the matter, you simply cannot put two bodies into the same space. The existence of the theory of chains of polarised particles and repulsion cannot continue. Once obtain a chain of polarised molecules, the space occupied by that chain is impervious to any other chain and any attempt to place other molecules polarised or not in that particular space is opposed. Many writers have attacked this theory of repulsion, but as we say it continues to be taught because of its convenience to the mathematicians. Just as it takes a certain force to drive a nail into a block of wood, and we might term this force the repulsion of the wood, so it takes a certain force to remove one set of molecules from a given position and replace them by another set. Assume then that the theory of chains of polarised particles has some ground for being believed. Let us examine what happens when such lines, loops, or chains are brought into contact. The magnetic lines of force, just like the current select the path of least resistance for the greatest action, and if when complete a foreign body is brought within the influence of the circuit offering a path of less resistence than that originally followed, the lines change their old path for the new, or divide themselves in inverse proportion to the resistance. There also seems to exist the property of shortening the path when such shortening is possible. It is this shortening property which forms what is termed the power of attraction. Let Figs 41, and 42, represent magnets with polarised chains as shown. Let the shaded portion represent the positive part of the polarised particles.

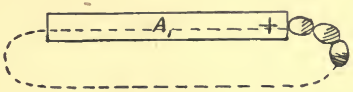


FIG 41.

When polarised the arrangement of the particles in the circuit is such that the + half of one particle is contiguous to the — half of the next and so on. If the fields are brought into contact, there will still be continuity of polarisation when the + pole is brought nearer or into contact with the — pole, and the previously double field becomes one, and the total resistance is lessened. The fields as it were try to shorten up when opposite poles are brought near each other, or put another way if the field of B comes within the influence of the field of A with opposite polarity either —to + or + to— there is, as it were, an attractive force exerted to bring the opposite poles into contact. If, however, similar poles are brought together as in Fig 43, and

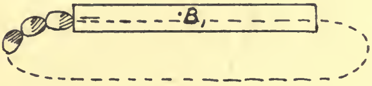


FIG 42.

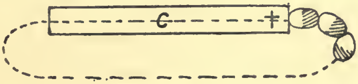


FIG 43.

Fig 44, it will be at once seen that continuity of polarisation will not be kept up if the particles join, and as the force under which they act is a polarising force they have no tendency to join, and wont join. The efforts to bring the similar poles together is an effort to put two sets of lines in the same space, and there is a resistance to this just as there is to put two masses of iron into the same place, and to this resistance the name repulsion has been given. If we conventionally use the terms attraction and repulsion, the convention admits of the simple rule.

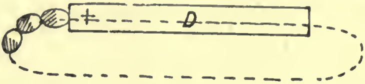


Fig. 44.

Unlike poles attract, like poles repel.

Similarly the inductive fields set up by currents cause

Unlike currents to attract, like currents to repel.

It is impossible to lay too much importance to the simple statement that no electric or magnet phenomena occur in bodies that are outside the circuits. In order to obtain the phenomena in any body it must form a part of the circuit. In practical work it is sometimes necessary to ensure one field not being interfered with by any other field, and apparatus is frequently enclosed in material to guard it from any such interference. This is especially the case in galvanometric apparatus to be used on board ships for cable work, frequently in telegraph work. When two or more distinct fields are permitted to interfere particularly in delicate work such as telephonic work, it is impossible to obtain good results. Hence the necessity of thoroughly studying all the phenomena connected with interference of circuits.

CHAPTER III.

HOW TO PRODUCE ELECTRICAL PRESSURE.

Apparatus. The apparatus constructed to generate electrical pressure may conveniently be divided into four classes, though the fundamental effect in each case may be taken as chemical:

1. Induction or frictional apparatus.
2. Batteries.
3. Dynamos.
4. Thermo-electric apparatus.

Induction or Frictional.—This was the earliest known apparatus for obtaining electrical phenomena. A piece of amber or a piece of dry glass, a rod of ebonite or of sealing-wax, etc., rubbed with a piece of dry silk will attract small pieces of paper or pith. But a more convenient apparatus than this was first introduced in the latter part of the seventeenth century, which developed into the well-known cylinder and plate-glass machines. Dr. Gilbert, in 1600, in his *De Magnete*, mentions a number of substances having this attractive property, as amber, gagates, diamond, sapphire, carbuncle, iris gemma, glass, hard resin, etc., and Sir Isaac Newton, in 1675, communicated a paper to the Royal Society on the subject. Stephen Gray, in papers commencing with 1720, describes his experiments, which resulted in a kind of electric telegraph, and the better knowledge of conductors and non-conductors. The work of these and a dozen other early experimenters is a fascinating study, especially to those who are interested in the archæology of the telegraph. This class of machine, too, is useful in the study of the inductive circuit. The best is that of Wimshurst. The ordinary pressure from these machines is about 10,000 volts, but a pressure of 40,000 or 50,000 volts is easily obtained.

Fig 45, shows the old form of plate machine AA is the glass plate BB are rubbers clamped to the frame and between which the glass is rotated by means of the handle G. A flap of black silk C partially covers the glass and serves to prevent conduction from that part of the plate through the air. The conductor D has its ends bent round the plate, the inside of the curved part being furnished with metal points said to collect the electricity but really diminishing the resistance of the circuit in a par-

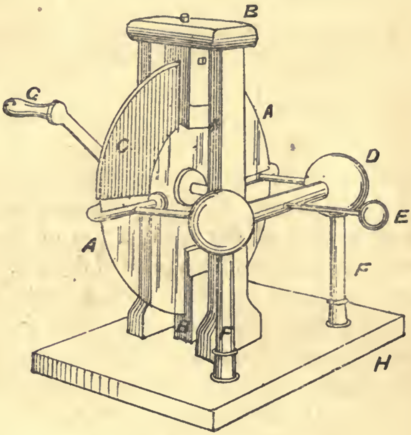


Fig. 45.

ticular direction, E is a knob on the conductor serving as the point in the circuit from which to charge a Leyden jar or a condenser or to obtain other phenomena, FF are

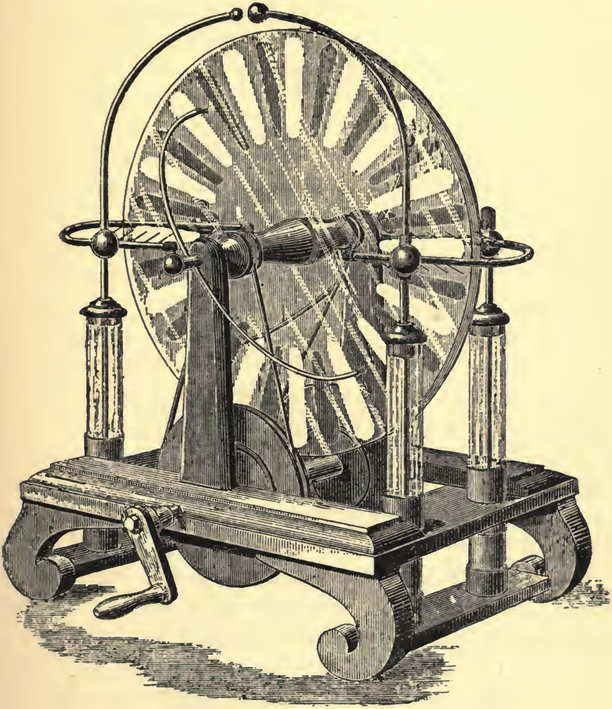


FIG. 46.

the insulated supports of the conductor, and H the base of the machine.

Wimshurst.—The Wimshurst machine, Fig 46, was designed about the year 1883. It consists of two circular discs of thin glass, attached to loose bosses revolving on a fixed horizontal spindle, in such way as to be rotated in opposite directions at about one-eighth of an inch apart. Each disc is driven by a cord or belt from a large pulley, of which two are attached to a spindle below the machine, the spindle is rotated by a handle, the difference in the direction of rotation of the discs being obtained by the crossing of one of the belts. Both discs are well varnished, and attached by cement to the outer surface of each, are twelve or more radial sector-shaped plates of thin brass or tinfoil, disposed around the discs at equal distances apart. It appears, probable that the sectors acting for the time as carriers on the one disc, act at the same time as inductors to the other. The two sectors situated on the same diameter of each disc are twice in each revolution momentarily placed in metallic connection with one another by means of a pair of fine wire brushes attached to the ends of a curved rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate; the metal sector-shaped plates just grazing the tips of the brushes as they pass them. The position of the two pairs of brushes with respect to the fixed collecting combs, and to one another, is variable, and there is, as in the case of the collecting commutator-brushes of dynamo-electric apparatus, a position of maximum efficiency. This position appears to be generally when the brushes touch the disc on diameters situated about 45° from the collecting combs, and the curved rods on the two sides are at right angles to one another, as shown in the engraving.

The fixed conductors consist of two forks furnished with collecting points directed towards one another and towards the two discs, which rotate between them; the position of the two forks, which are supported on insulating supports of some kind being along the horizontal diameter of the disc. To these collecting combs are attached terminal knobs, whose distance apart can be varied by projecting ebonite handles, or otherwise.

With a machine composed of two glass plates only 14½ inches in diameter there is produced, under ordinary atmospheric conditions, a powerful spark discharge between the knobs when they are separated by a distance of 4½ inches, a pint-size Leyden jar being in connection with each knob; and these 4½-inch discharges take place in regular succession at every two and a half turns of the handle. It is usual to construct the machine as shown in the illustration, with small Leyden jars or condensers attached to conductors, by which the spark is materially increased.

This machine is self-exciting, though the self-excitation is found to depend somewhat on the number of sectors. With a higher number the machine excites itself very freely, but the sparks are more feeble; with fewer sectors it is less easy to excite, but the sparks are much more powerful when obtained.

When using induction machines the moisture of the air often causes experiments to fail. The atmosphere becomes saturated with moisture, and it is often impossible to get the machine in working order. Toepler tries to prevent this by placing the whole machine on a kind of stove. The Wimshurst machine and that of Carré are the least subject to these defects of any that we are acquainted with.

Leyden Jar and Condenser.—For many experimental purposes an inductive circuit is formed by using a Leyden jar, the conductors on the surfaces of which are placed respectively in conductive connection with the conductor and the rubber of the machine. Fig 47, shows an ordinary form of Leyden jar which consists merely of a glass vessel coated three parts up inside and outside with tinfoil as shown in section at A and B. A metal knob is metallically connected to the interior tinfoil as shown. When

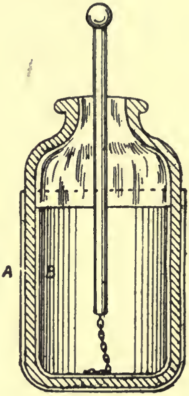


FIG. 47.

charging, the Leyden jar has its exterior coating connected to one pole of the machine, its interior to the other, the glass being the dielectric. It will be seen at once that

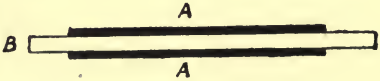


FIG. 48.

the same effect is obtained by taking a flat piece of glass, B, Fig 48, coating it with tinfoil, A_1 A, on both sides, and putting A into contact with one pole, and A_1 with the other.

This latter form is termed a condenser, but in condensers intended for practical work the dielectric is usually paraffin, and the strips of conductor are more numerous. Thus, Fig 49, by a number of strips of conductor, A, A, A, separated from other strips, A_1, A_1, A_1, by paraffin, all the A strips being connected to a terminal, T, and all the A_1 strips to a terminal, T_1, we decrease the dielectric resistance and increase the accumulation. Condensers of this kind are largely used in duplexing submarine cables. The cable itself is like a long Leyden jar, and in working, it acquires a charge, which charge has to be balanced to obtain the conditions necessary for duplex working. Condensers are also used to increase the effect of induction coils.

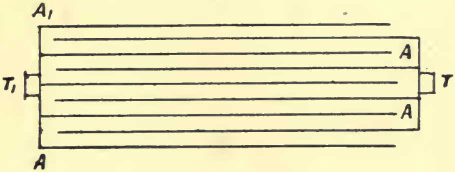


Fig. 49.

Batteries.—This class of apparatus is due to the investigations of Galvani and Volta. Of the making of batteries there is no end, but of the hundreds that have been devised only four or five will be mentioned here. A good battery requires the properties of high electric pressure, constancy, longevity, and low internal resistance. No combination gives more than about two volts pressure, but it is easy to add the pressure of cell to cell so that any required pressure may be obtained. A single combination, such as that shown in Fig 50, is termed a cell, and a battery is composed of one or more cells.

Contact v. Chemical Theory.—The generation of electrical pressure has been attributed by one school of philosophers to the *contact* of two different metals or substances, and by another school to the *chemical action* of one substance upon another. The controversy seems to us to touch upon the ridiculous, for a little consideration will reduce both contact and chemical to one, and that one is chemical. It is well known that chemical changes are produced in some substances when they come into contact with certain other substances. It is also as well known that the force which causes chemical action is exerted only at insensible distances, and frequently the mere bringing into ordinary contact does not bring the substances within the distance at which chemical action can take place. Further, it may be assumed that the substance, or substances, chemically acted upon undergo a preparatory change before the commencement of the

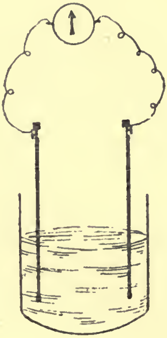


Fig. 50.

action. At what distance this preparatory change commences is not known, but we hold it probable that it is this preparatory change that gives support to the contact theory. At any rate if contact sets up the pressure, chemical action is required to continue it. From these remarks it will be inferred, and justly so, that the effective pressure obtained depends upon the materials selected in the combination.

The Couple.—A combination or a cell generally consists of two dissimiliar metals immersed in a conducting liquid, which acts chemically upon one of them. The metal acted upon is termed the + or the electro-positive, the other the − or the electro-negative plate. The following is a list of metals, commencing with the most electro-positive when immersed in dilute sulphuric acid. The order may be slightly changed when immersion is in some other electrolyte.

+ Zinc, tin, lead, iron, nickel, bismuth, antimony, copper, silver −

From these metals the greatest effective pressure in dilute sulphuric acid would be with the couple zinc and silver, but as silver is expensive and very little better than copper, zinc and copper is a couple frequently used.

Those who desire to investigate the relative electrical positions of the various metals and other substances in different electrolytes, will find a very comprehensive account of the whole matter in Dr. D. Tommasi's book on batteries. Perhaps the most thorough investigation on the subject is that by Dr. Gore, of Birmingham, who tabulates the position of some two dozen substances in various solutions at various degrees of concentration and different temperatures.

Constancy.—If a simple combination of zinc and copper in dilute sulphuric acid is taken as in Fig. 50, it will be found when external contact is made that the copper plate is covered with minute bubbles of gas, which increase in size and come rapidly to the surface. If the gas is collected and tested it is found to be hydrogen. Starting then with the couple zinc and copper, as soon as the copper plate is covered with hydrogen we get another couple, zinc and hydrogen, and the tendency of this couple is just the opposite of the original one. Assuming then that the electrical pressure originally acts from Zn to Cu, under the new conditions a reverse pressure is set up from hydrogen (H) to zinc (Zn). This is smaller than the original, and the result is an electrical pressure from Zn to Cu, but diminished by the counter pressure H to Zn. It will at once be seen that constancy cannot be obtained by a combination of this kind, so many attempts have been made to add something to the original combination that should combine with the hydrogen, keeping the copper plate clear and interfering no further with the electrical action, and thus be enabled to get a constant electrical pressure, which would, of course, through a constant resistance give a constant current. Prof. Daniell was the first to solve the difficulty, and the battery known as Daniell's will now be described.

Daniell's Battery.—A Daniell's battery is generally constructed of an outer case of copper, Cu, a porous earthenware pot, D, and a rod of zinc, Zn. Binding screws for fastening the external conductors are fixed to the zinc and copper. The zinc rod is amalgamated; for ordinary commercial zinc, when used as the active plate of a battery couple, is liable to be uselessly wasted when not required by local action, due to couples arising between the zinc and the impurities it contains. To prevent this local action, the zinc is amalgamated by being first cleaned with sulphuric or by hydrochloric acid and then rubbed with mercury. The mercury forms an amalgam with the zinc, which, so far as electrical action is concerned, has all the properties of pure zinc at a much less cost. The mercury can be rubbed on the zinc by means of a clean rag. The amalgamated zinc is placed in the porous pot, which is then nearly filled with dilute sulphuric acid, one part acid to eight of water. The outer jar is nearly filled with a solution of sulphate of copper. A perforated ledge, or a kind of perforated pocket in the outer jar, permits a quantity of the sulphate of copper to be kept in the cell so as always to have a saturated solution. The action is somewhat as follows:

$$\overset{\mathrm{Cu}}{\Big|}\quad \mathrm{CuSO_4}\quad \Big|\quad \mathrm{H_2SO_4}\quad \overset{\mathrm{Zn}}{\Big\|}\quad \mathrm{H_2SO_4}\quad \Big|\quad \mathrm{CuSO_4}\quad \overset{\mathrm{Cu}}{\Big|}$$

The sulphuric acid in contact with the zinc plate is decomposed, forming sulphate of zinc ($ZnSO_4$), the H liberated decomposes the sulphate of copper ($CuSO_4$), forming H_2SO_4, setting free Cu, which is deposited upon the copper plate. Thus the copper plate is always kept clean. The conditions before and after the circuit is closed is thus shown:

Before	Cu	$CuSO_4$	H_2SO_4	Zn
	Copper.	Sulphate of Copper.	Sulphuric Acid.	Zinc.
After	Cu Cu	SO_4H_2	SO_4Zn	
	Copper on Copper.	Sulphuric Acid.	Sulphate of Zinc.	

Grove's Battery.—A modification of Daniell's battery is that of Grove, wherein nitric acid takes the place of sulphate of copper, and a platinum plate that of the copper plate. The action may be shown thus:

Before closing circuit $H_2O + N_2O_5 = 2HNO_3$

Pt	N_2O_5	H_2SO_4	Zn
Platinum.	Nitric Acid.	Sulphuric Acid.	Zinc.

After

Pt	N_2O_4	OH_2	SO_4 Zn
Platinum.	Nitrous Acid.	Water.	Sulphate of Zinc.

The Bunsen battery is similar to Grove's, except that a carbon plate is substituted for platinum.

The Leclanche Battery.—This battery is not so constant as the others mentioned, but it is largely used for such purposes as electric bell work, where intermittent currents are wanted, and although it rapidly polarises on closing the circuit, it soon recovers its full electrical pressure. Another good feature about this battery is that it is less liable to local action than the Daniell and many others. In it the zinc plate is put into a solution of salammoniac, while the carbon plate is surrounded with crushed binoxide of manganese. The action may be indicated

Before	C	$2MnO_2$	$2NH_4Cl$	Zn
	Carbon.	Binoxide of Manganese.	Salammoniac.	Zinc.

After	C	Mn_2O_3	H_2O	$2NH_3$	$ZnCl_2$
	Carbon.	Sesquioxide of Manganese.	Water.	Ammonia.	Chloride of Zinc.

Secondary Batteries.—The batteries hitherto mentioned and scores of similiar batteries are called primary batteries, in contradistinction to another class that has lately been developed for practical use, termed secondary batteries. In primary batteries, the materials when once used have to be renewed. In secondary batteries, on the contrary, the materials can be renovated and used over and over again. If we take a couple consisting of two lead plates in dilute sulphuric acid, and place the couple in a conductive circuit as in Fig 51, one of the lead plates becomes coated with a thin coating of lead peroxide. If now this cell is taken out of the circuit and placed in a circuit of its own, of which it forms the source, on completing the external circuit, a current passes in the external circuit from the oxidised plate to the other plate. The cells then are reversible. A current passed through them produces certain chemical changes. The sending of the current through the cells is called charging. When the cells are discharged they form the source of the electrical pressure and current. During discharge reverse chemical changes take place, the combination thus regaining its original state. In practice, however, they are only partially discharged and then recharged. By using lead plates alone only a comparatively small effect can for a long time be obtained, the plates getting better and better after numerous chargings and dischargings till the plate that is oxidised becomes thoroughly porous, and offers a very large surface to the action of the

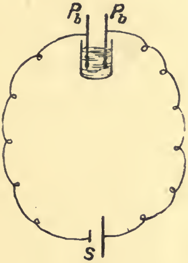


FIG. 51.

electrolyte. To save the time and cost of "making plates," that is, getting thoroughly porous plates, numerous devices have been put forward till the best of the modern secondary batteries consists of a "grid," which is cast of an alloy of lead and antimony. The holes in the grid taper outwards. The plates intended for positives are filled up with a paste made of red lead and sulphuric acid, the negatives being filled with a paste of litharge and sulphuric acid. The exact chemical change that takes place in charging and discharging these lead reversible batteries is not definitely settled. M. St. Drzewiecki believes the positive plate after charge to be coated with a combination having the formula $H_2Pb_2O_7$, and this after in discharge is reduced to PbO_2. The negative plate after charge consists of lead hydrate 2HPb, and after discharge of a mixture of hyposulphate and sulphate of lead.

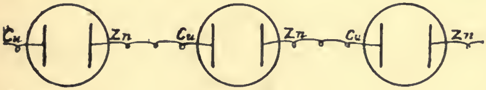
Longevity.—The length of life of a battery depends upon the work it has to do, the attention paid to it, and the amount of local action that takes place. With regard to secondary batteries, there is no real trustworty data to enable a correct judgment to be formed. With careful attention ten years should be a short life for this class of battery.

Internal Resistance.—The internal resistance of a cell depends upon the surface area of the opposed plates, the electrolyte used, the condition of the electrolyte, the quality of the porous pot, and the distances between the plates.

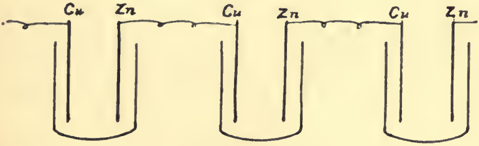
Arrangement of Batteries.—The battery must be selected, and arranged with due consideration for the work it has to do. In the first place, it is necessary to have sufficient electrical pressure to overcome the resistance in the circuit. This resistance may be divided into two parts, one external to the battery, the other the internal resistance of the battery itself. Hence we may write Ohm's formula

$$C\;R=\frac{E}{R+r}.$$

When R = the external resistance, and r the internal resistance. To obtain the desired pressure, cells are connected in series as in Fig 52. If n cells are placed in series, then



Plan.



Section.

Fig. 52.

the electrical pressure, E, is increased n times, and the internal resistance is also increased n times. The formula then becomes

$$C=\frac{n\,E}{R+n\,r}.$$

The available pressure for use in the external circuit is not increased n times, but something less, considerably less if the internal resistance is large. Thus, we have one reason for keeping the internal resistance as low as possible—viz., that as much available pressure as possible shall be had for use in the external part of the circuit

When the external resistance, R, is very small, as when the poles are joined by a short, thick, good conductor, and can be neglected, the above formula becomes

$$C = \frac{nE}{nr},$$

little of the current developed by the pressure is then practically utilisable. When R is so small that nearly the whole current goes through the internal part of the circuit, the battery is said to be short-circuited.

If there are difficulties in the way of getting E sufficiently large because of the resistance r, we can arrange cells to diminish r, still having E as large as we require.

By arranging n cells in parallel or in multiple arc, as in Fig 53, we decrease the internal resistance n times, for

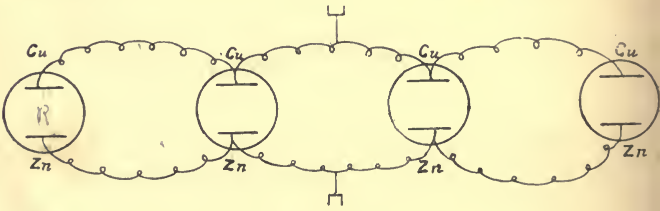


Fig. 53.

the arrangement is similar to having one cell, with plates n times as large as previously, the distance between the plates remaining the same. The formula now becomes

$$C = \frac{E}{R + \frac{r}{n}} = \frac{nE}{nR + r}.$$

If r is small compared with nR it may be neglected, and we again get

$$C = \frac{nE}{nR} = \frac{E}{R},$$

that is, the available pressure is almost all used in the external circuit when r is small. Figs 54, and 55, show two ways of arranging six cells. In Fig 54, we get E three times that of one cell, and r half as much as in one cell. In Fig. 55, E is twice that of one cell, and r is one-third of that of one cell. Such arrangements are called multiple series arrangements. Thus, we have three ways of arranging cells in batteries—in series, in multiple arc, or in multiple series.

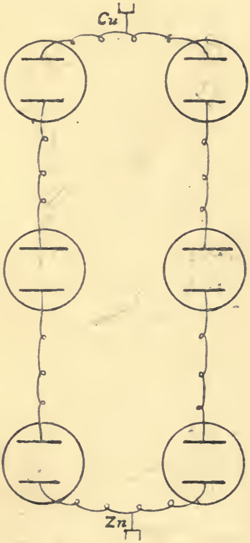


FIG. 54.

The formula put into figures—say, for 6 cells of 2 volts each, with internal resistance ·5 ohm, and say $R = 12$ ohms, become

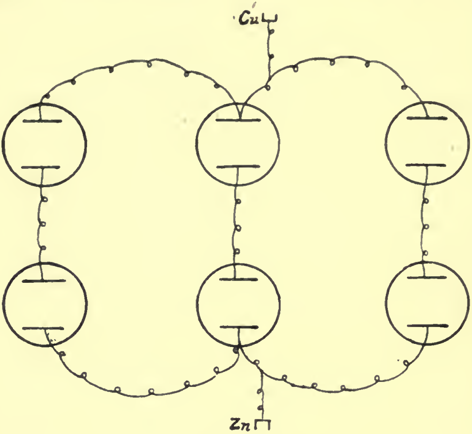


FIG. 55.

1. In series:

$$C = \frac{n\,E}{R + nr}$$

$$C = \frac{6 \times 2}{12 + (6 \times \cdot 5)} = \frac{12}{15} = \cdot 8 \text{ ampere.}$$

2. In multiple arc:

$$C = \frac{E}{R + \frac{r}{n}} = \frac{2}{12 + \frac{\cdot 5}{6}} = \cdot 16 \text{ ampere (about).}$$

3. In multiple series as in Fig. 54:

$$C = \frac{\frac{n}{2} \times E}{R + \frac{r}{2}} = \frac{3 \times 2}{12 + \cdot 25} = \frac{6}{12{\cdot}25} = \cdot 49 \text{ ampere.}$$

4. In multiple series as in Fig. 55:

$$C = \frac{\frac{n}{3} \times E}{R + \frac{r}{3}} = \frac{2 \times 2}{12 + \cdot 16} = \frac{4}{12 \cdot 16} = \cdot 33 \text{ (about)}$$

DYNAMOS.

The Modern Dynamo.—The reader must consult larger books to obtain a knowledge of the history of the development of the dynamo since Faraday first published his experiment upon the interaction of conductive and magnetic circuits. A long roll of names will be found of men who have designed apparatus or investigated theories, each adding to our knowledge of the subject. The men, however, who have done most to perfect the modern dynamo are Hopkinson and Kapp, in that their investigations have enabled us to work by rule, to specify and to obtain that specified—not only to tell what a dynamo will do after it is made, but to tell what it will do before it is made. Others have added lines to their pages, and rounded off some of the corners of their investigations, but these men stand far before all others in the matter of obtaining results capable of being practically used to construct machines. Before entering upon the consideration of the dynamo it will be necessary to prepare the way. Hitherto the formulæ used have been exceedingly simple, involving really only a little arithmetical knowledge. It is desirable, however, that the student should understand something of graphical formulæ, and although a full knowledge of these would involve an acquaintance with higher mathematics, no such knowledge is required in this elementary work.

Electro-Graphics.

The ancient Assyrians and Egyptians used a hieroglyphic literature, so does the modern scientific man. The latter uses lines and curves to represent many things, and frequently a line or curve rightly interpreted will speak more clearly and more plainly than many pages of type.

A point is used to indicate a certain position in space. From a point or to a point a line may be drawn, and this line will indicate magnitude as well as direction. Thus we may indicate a force as acting at the point O in the direction of OX, and if the force is of so many pounds or tons, the length of OX can indicate how many pounds or tons, if we agree that a certain length shall indicate one pound or one ton.

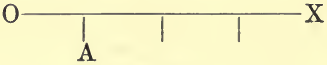


Fig 56.

Thus, if OA represents one pound OX will represent four pounds, if OA represent one ton OX will represent four tons. Instead of one force acting upon a body at the point O in the direction and of the magnitude OX, there

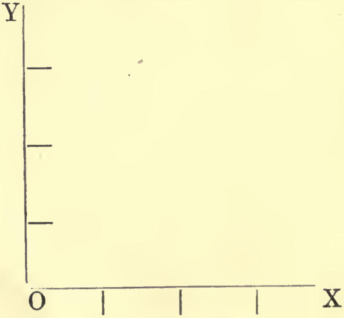


Fig. 57.

may be two or more forces acting at the point in the same or in other directions. For example, we may have a force in the direction OY at right angles to OX, similarly represented in direction and in magnitude by OY.

If two forces act upon a body at O the body will not move in the direction of either of those forces, except the direction in which they act is in the same straight line. Thus, if two forces, A and B, act upon a body at O in the direction shown by the arrows, and of magnitude proportional to the lines, the body will move or tend to move in the direction OA. $\overset{B}{\longleftarrow} O \overset{A}{\longrightarrow}$

If the forces are not in the same straight line, but act at any angle, the body moves or tends to move in a direction somewhere between the direction of the forces. If the two forces are constant in direction and in magnitude, the resultant direction in which the body moves or tends to move is a straight line. This line, when obtained, is said to be "the resultant of the forces." Its direction and magnitude in the simple case mentioned, that of forces acting along OX, OY, and of the magnitude OX, OY, can easily be obtained by completing the parallelogram, of which OX, OY form adjacent sides, and drawing the diagonal OZ. Then OZ is the resultant in magnitude, and in direction of the forces OX, OY acting upon O at the point O in the

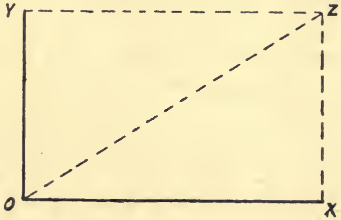


FIG. 58.

direction OX, OY. Similarly the resultant of any two forces can be found by drawing the diagonal of the completed parallelogram. If the forces are not constant in direction or in magnitude, then the direction of the resultant will probably be a curve. Thus we see how lines and curves can be utilised to indicate the direction and magnitude of forces, and the "resultant" of forces in magnitude and direction.

Let A B, A C, Fig 59, represent forces of 4lb. and 3lb. respectively acting in the directions A B, A C. The resultant is found by completing the parallelogram A B C D, by drawing through C the line C D parallel to A B, and through B the line B D parallel to A C. Join A D. Then A D represents the resultant of the force A C, A D in direction and in magnitude—that is, the same effect would be obtained if A C and A B were replaced by a force represented in direction and in magnitude by A D. If A B, A C act at right angles to each other, and be drawn to scale, A B = 4 units, and A C = 3 units, then A D will on the same scale measure 5 units. For the angle A B D being a right angle,

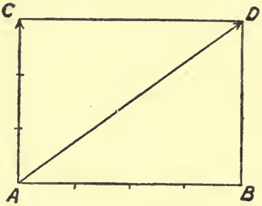


FIG. 59.

$$\mathrm{A\ B}^2 + \mathrm{B\ D}^2 = \mathrm{A\ D}^2$$

$$4^2 + 3^2 = \mathrm{A\ D}^2$$

$$\sqrt{25} = 5 = \sqrt{\mathrm{A\ D}^2} = \mathrm{A\ D}.$$

The resultant of two forces acting at any other angle than a right angle may be similarly represented, though in many cases the calculation is not so simple. We may take a simple example and show how easily it can be solved :

Two forces represented by 12lb. and 15lb. acting upon a point at an angle of 60 deg., required to find the magnitude and direction of the resultant,

1st. Graphical solution, Fig 60.

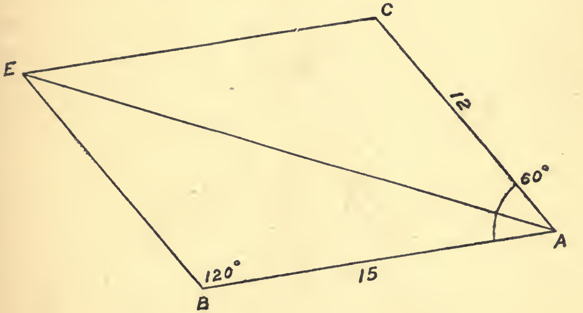


Fig. 60.

Draw A B = 15 units of any convenient scale.

Make the angle B A C = 60 deg.

Make A C = 12 units of same scale as A B.

Through C draw C E parallel to A B, and through B draw B E parallel to A C.

Join A E. Then A E is the resultant of A B, A C, and if measured off on the same scale as was used in drawing A B, A C will be found to be 23 2-5 parts of that scale. The angle B A E will be found to measure very nearly 26° 20′. The resultant force then is 23 2-5lb.

2nd. Calculation:

$$
\begin{aligned}
AE^2 &= AB^2 + BE^2 - 2\ AB,\ BE,\ \cos.\ 120\ \text{deg.} \\
&= AB^2 + BE^2 + 2\ AB.\ BE,\ \cos.\ 60\ \text{deg.} \\
&= 15^2 + 12^2 + 2 \times 15 \times 12 \times \cdot 5. \\
&= 549. \\
AE &= \sqrt{549} = 23\cdot 43.
\end{aligned}
$$

An answer which differs from the preceding one only by $\cdot 03$, or $\frac{3}{100}$.

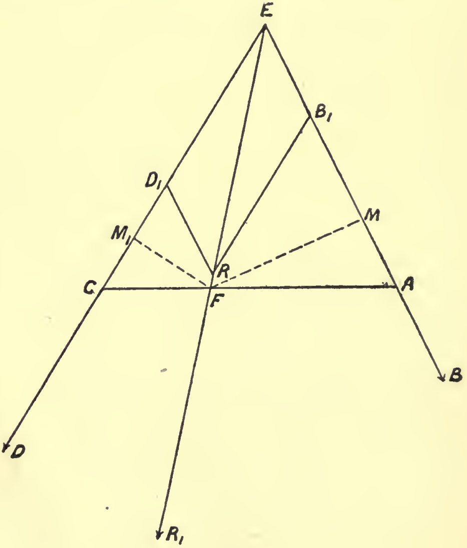


FIG. 61.

If more than two forces act upon a point, their resultant may be found by first finding the resultant of two of these of the forces, then of two more, then the resultant resultants, and so on.

Moment of Forces, Couples, Torque.—Forces may not act at the same point on a body, Fig 61.

Let the two forces P and Q, represented in magnitude and direction respectively by AB, CD, act respectively at the points A and B on a body. The resultant of these forces can be found. Also the point at which it acts, graphically thus—Join AC. Produce DC, BA to meet at the point E. Along EC take $ED_1 = CD$, and along EA take $EB = AB$. Complete the parallelogram EB_1 RD_1. Join ER. Produce ER, cutting AC in F and make $FR_1 = ER$. Then FR_1 represents the resultant of AB_1 CD, and AB_1 CD may be replaced by the single force FR_1 acting at F.

From F draw FM, FM_1 perpendicular to the direction of the forces AB_1 CD respectively. It is found that the force P represented by $AB \times FM =$ the force Q represented by $CD \times FM_1$ or shortly, $P \times FM = Q \times FM_1$

These products are termed the moments of the forces.

If the body acted upon be reduced to a rigid line AC, AC is called a lever, and the point F its fulcrum. If the force P alone were to act on the body at the point A, or, say, on the lever, it would evidently twist the lever about the fulcrum, and Q, acting alone at C, would twist the lever about the fulcrum in the opposite direction. When two equal and opposite parallel forces act at different points of a rigid body in the same plane, their effect cannot be obtained by a single or resultant force, and their tendency will be to twist the body in the direction of the plane in which they act. Thus P, Fig 62, acting on A in the direction AP, and P acting on B in the direction BP, will twist the body round in the direction BAP or ABP.

The term Couple is applied to such a system of forces.

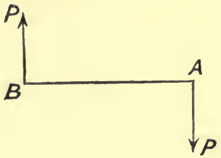


Fig. 62.

The product of one of the forces and the arm of the couple is called the moment of that couple. Thus P × A B = moment of the couple represented in Fig 62. This applied to a magnet gives the magnetic force at the N pole or at the S pole × the length of the axis of the magnet as the moment of the magnet.

This moment is a measure of the tendency of the couple to twist the body on which it acts, and it is customary to indicate a couple by its moment.

A couple tending to twist a body in the same direction as the hands of a watch is termed a positive couple; if in the opposite direction, a negative couple. The term "torque" is generally used by electrical engineers instead of "moment of couple," "statical-moment," or "turning moment."

The product of two quantities can be represented by an area.

This kind of graphic representation is principally due to Prof. Sylvanus Thompson. An example, taken from his well-known book, will show the excellence and the simplicity of his work. It relates to the efficiency of motors and is at once simple and fully within the comprehension of those who have acquired a rudimentary knowledge of geometry. Let A B, Fig 63, represent the electro-motive force, E, of the electric supply. On A B construct the

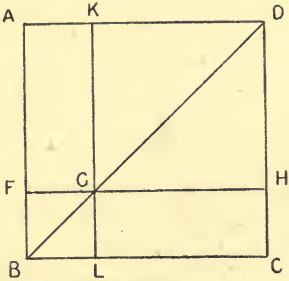


FIG. 63.

square A B C D. Draw the diagonal B D. From B along B A measure B F, representing on the same scale the counter electromotive force of the motor. Through F draw F G H parallel to B C, and through G draw K G L parallel to A B or D C. The actual electromotive force producing a current is the difference between the electromotive force of the supply and the counter electromotive force of the motor. Let the latter $= e$. The difference is $E - e$, which may be represented by A F, K G, D H, K D, G H, or L C. The electric energy put into the motor per second is $C^2 R = E C$; and as $C = \frac{E - e}{R}$, where $R =$ total resistance in the circuit, C is represented in the diagram by $\frac{\mathrm{F\,A}}{\mathrm{R}}$, for F A = A B — B F = E — e. The energy expressed thus may be written $\frac{\mathrm{E}\,(\mathrm{E}-e)}{\mathrm{R}}$.

The work converted by the motor is

$$\frac{e\,(\mathrm{E}-e)}{\mathrm{R}},$$

but R is constant, so that these values may be written respectively E (E – e) and e (E – e).

Now the product E (E – e) is represented by the rectangle A F H D, for A D = A B representing E; and A F represents E – e.

While the product e (E — e) is represented by the rectangle G L C H, for G L = F B represents e, and G H = G K = A F represents E — e.

These areas, then, are proportional to the work expended

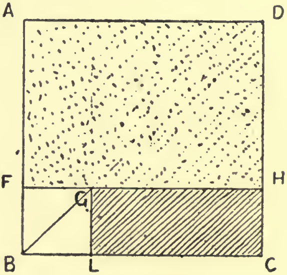


Fig 64.

and recovered, and when shaded, as in Fig 64, exhibit very clearly these proportions.

It will be seen that the construction of such diagrams is very simple, but when carefully constructed can be made to give considerable information to those who might be unable to understand analytic treatment.

The Use of Co-Ordinates.

The third kind of graphic representations to which we shall briefly allude are those in which it is usual to define the position of a line by referring to its distance from two other lines generally at right angles to one another in the plane of the paper. The branch o mathematics that treats this subject fully is termed co-ordinate geometry. As an instrument of research the co-ordinate theory is unequalled for power and facility. Assume that lines, whether straight or curved, are made up of a series of points. It will be best to consider first the position of a point in a plane, then to consider series o points or lines.

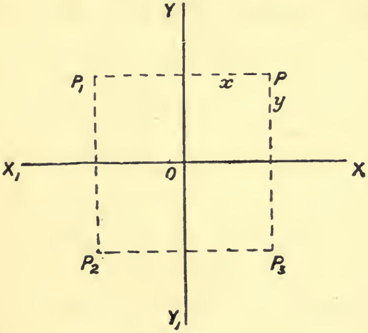


FIG. 65.

The position of a point is determined when we know its distance from three plane surfaces. It is sufficient, however, in diagrams, where both lines and points are in the plane of the paper, to determine the position of a point by its distance from two lines. For diagrammatic or hieroglyphic purposes the lines to which the distance is referred are generally at right angles, as XOX_1, YOY_1. The exact position, then, of a point P is determined if we know its distance from XOX_1 and YOY_1. But another convention comes in : all positions to the right of YOY_1 are termed positive as regards YOY_1, similarly all positions above XOX_1 are positive as regards XOX_1. Now a point P may be in either of the four quadrants as P, P_1, P_2, P_3. Suppose we know P is x inches from Y and y inches from X, we can measure off x inches along OX and y inches along OY, and from these points draw lines parallel to OX and OY respectively. Where these lines intersect will be the point P. If the distance be $-x$ and $+y$ we know the point is in quadrant X_1OY ; if $-x$ and $-y$, in quadrant X_1OY_1 ; if x and $-y$, in quadrant XOY_1 ; and thus the position of a point is fully determined. The lines OX, OY are called axes, O the origin of the axes, x and y are called ordinates; y is called *the* ordinate and x the abscissa of the point P. Usually in simple cases only one quadrant is required, YOX. It will at once be seen that if we can determine the position of one point we can determine the position of any number of points, and a succession of points will produce a straight or a curved line. Experimental and constructional work frequently requires the determination of a number of points. Joining the points gives lines and curves from which information can be deduced, and sometimes laws obtained. Let us take a practical example. When a piece of iron is subjected to magnetic pressure, it is said to be magnetised—that is, it has a certain number of lines of force, or lines of induction, sent through it as previously explained. If, then, equal parts of OX are taken to represent equal additions of magnetic pressure, the number of lines in the iron will increase with the increase of pressure. Equal distances along OY can be taken to represent equal number of lines of force. Thus the magnetism due to pressure a is seen to be a_1, due to pressure b is b_1, to pressure c is c_1, and so on. If the divisions of OX, OY represent numerical values, as they are usually made to do, a large amount of in formation is graphically put into a small space. The placing the points c, c_1, c_2, etc., obtained by the experiment, and subsequently joining the points, is called plotting the line or curve. Ruled paper for the plotting of such curves can be obtained at almost any stationers.

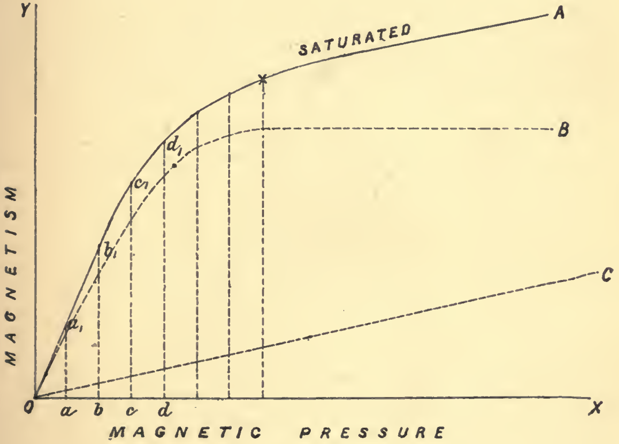


FIG. 66.

Principles of the Dynamo.—The broad features of the modern dynamo, those to which it owes its utility, are the interactions between the magnetic and the conductive circuits. Usually a conductive circuit is placed in and revolved in a magnetic circuit. The magnets used to obtain the magnetic field are called the field-magnets; that part of the conductive circuit revolving in the field is called the armature. It has been stated that the action in the conductive circuit is proportional to the number of loops, or closed curves of lines of force that pass around it due to the magnetic field. According to the views expressed in previous chapters, it will be found that the action of placing magnetic loops around a conductor is to diminish the electrical pressure in that part of the conductor so placed, and this diminution of pressure leads to

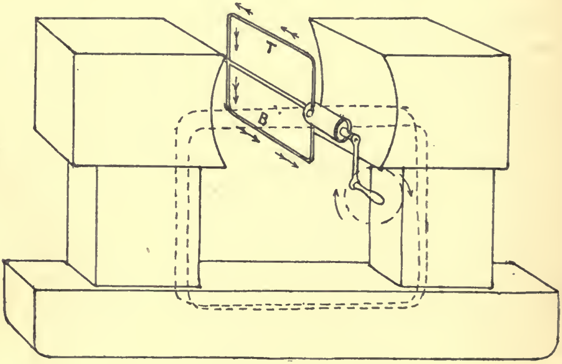


FIG. 67.

a flow of current in the conductor. It will easily be seen that the placing of a number of loops around a conductor leads but to a momentary current; if we increase the number of loops, further current in the same direction is set up; decrease the loops, and the current flows back and it is in the reverse direction; get rid of all the loops, and the current goes back altogether, and the conductor is in its normal state. Take a conductor, R, of a single turn, and place it in a magnetic field as in Fig 67.

Assume the direction of the loops to be from the pole N to the pole S. When the conductive circuit, R, is in a vertical position, the maximum number of magnetic loops due to the magnetic field, N S, pass around the lower portion of the circuit R, and there is in that part of the circuit a diminution of the electrical pressure, and a current is momentarily set up in the direction shown by the arrows. Turning the handle, H, in the direction of the hands of a watch, as shown by the arrow, so that R passes through a quarter of a revolution, the conductor then has the minimum number of loops passing around it, and in the revolution there has been a gradual diminution from the maximum number to the minimum, and as a result there has been a current in the reverse direction to the original current. Turning the handle another quarter of a revolution, that part of the conducting wire that was originally at the top, T, is now at the bottom, B, and has now the maximum number of loops around it, and the current will be the direction of the arrows—that is, just in the opposite direction to what it was when this part of the circuit was the top member of the system. The action through the whole revolution may be illustrated thus. Let the line AE represent the motion of the handle, AB the representing first quarter revolution, BC the second, CB the third, and DE the fourth. Suppose the circuit RTB at the start horizontal—that is, with minimum or no loops around it—the bottom member, B, being at the right-hand nearest to the pole N of the magnet. Directly the handle begins to move, loops are formed around B; the number of loops increase till the circuit is vertical. During this time the current in the circuit increases from its minimum to its maximum. Passing the vertical point, the loops around B diminish till the horizontal point is reached, when B is nearest the pole S. Passing this point, the loops begin to be formed around T, and a similar action to what has just been described happens in regard to T, the current rising from the minimum to the maximum, and decreasing again to the maximum. If F represents the maximum current, AFC, CFE will represent what goes on as regards current in the circuit. It is almost exactly that of the ebbing and flowing of the tide. The number of loops around the wire determines the electrical pressure at that point, the pressure being least with the greatest number of loops, and returning to the normal state with no loops.

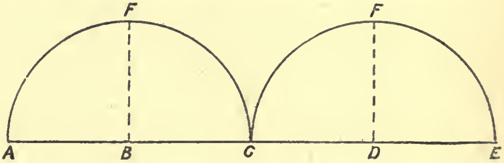


FIG. 68.

It will be seen then that one of the most important questions connected with dynamos is the number of loops that pass around the conductive circuit, as this determines the electrical pressure, and consequently the current. We have preferred to speak hitherto of loops, or the closed curves, as this seems more in accordance with facts, than of so many lines of force passing through the space enclosed by the conducting circuit. Passing through gives no reason for any alteration of electrical pressure in the circuit—passing round does—and that is the difference between us and previous writers. If we consider T as part of a complete circuit, we must then consider that during one half revolution current flows in one direction, and during the other half it flows in the other. This may be represented as in Fig 69, though in many machines arrangements are made that the current in the external part of the circuit shall always be in the same direction. These machines are called continuous current, while those in which the current is not so commuted are called alternate-current machines.

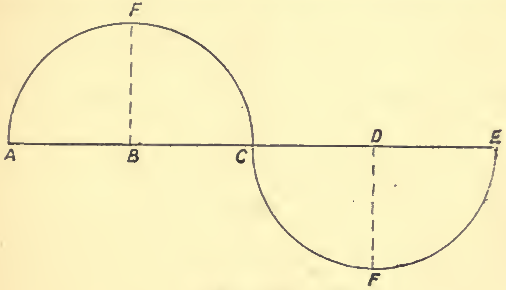


FIG. 69.

If, instead of assuming that the electrical pressure is diminished in proportion to the number of encircling loops, it is assumed that the pressure at another point in the circuit is increased in that proportion, the result will be the same—a current will be set up proportional to this pressure. The unit of electrical pressure is, as has been stated, a VOLT, and by the interaction of magnetic and conductive circuit we have means of :—

Obtaining the Pressure.—A volt pressure is obtained by looping around a conductive circuit 100,000,000 loops or lines of force *per second.* We have seen that the pressure with batteries is increased to the required point by adding cell to cell in series. A similar action occurs in the interactions now under consideration. If we place loops around different parts of the same circuit, the total electrical pressure obtained is the sum of the separate pressures. Instead, therefore, of using a circuit of one wire, it is customary to use circuits of a number of turns of the same wire. Thus, in Fig 70, if we have three turns around which the loops are passed, the pressure obtained is three times that which would be obtained by one turn with the same number of loops round it. This is not exactly the case, as the interactions between the turns themselves tend to somewhat reduce the pressure, as will be seen further on, but for the present we may take the pressure as proportional to the number of turns.

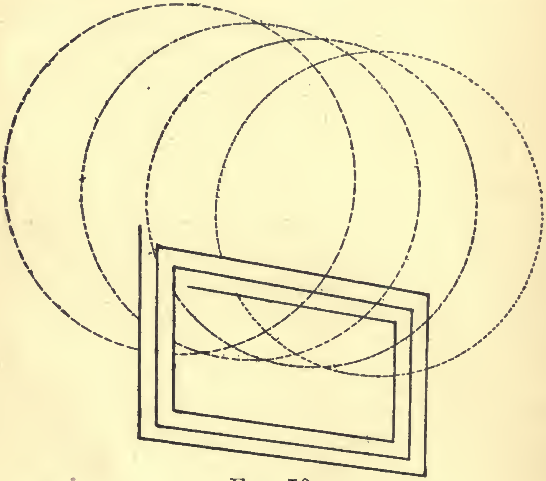


FIG. 70

Again, as the pressure obtained depends upon the number of loops put around the conductor per second, the faster the turns are revolved the greater will be the pressure obtained. Thus the number of loops around the conductor per second can be increased in various ways.

1. By increasing the intensity of the magnetic field—that is, increasing the number of loops per square inch.
2. By increasing the size of the field, and having a longer total length of conductor acted upon.
3. By increasing the number of turns in the armature coils or so winding that a greater number of turns are acted upon.
4. By increasing the number of revolutions per second.

In practical work it is impossible to carry any of these methods to extremes. Just as a conductor must not be used to carry too great a current, otherwise it will melt, so it becomes a costly process to magnetise iron much past the saturation point. Too large a field would mean cumbersome and heavy machines. The number of turns of wire depends on several considerations—such as size and space to be utilised. Speed is merely a question of mechanical conditions. But even with only the above conditions prevailing the different combinations are almost unlimited.

Obtaining the Field.—The field-magnets are generally electromagnets, although in a few cases, for example, De Meritens, uses the permanent magnet. The advantage is all on the side of the electromagnet, for the intensity of field obtained by the latter is far greater than with the former. Attention here will be directed exclusively to dynamos with electromagnets. The electromagnet consists of two parts, the core and the coil. The current in the coil determines the magnetic pressure, while the core determines the resistance of the magnetic circuit. The less the resistance of the core and the air space between its poles, the greater the number of closed lines of force obtained. The great want of to-day in practical work is a practical unit whereby to measure the number of lines of force. Every action of a magnet depends upon "number of lines" involved in the action. If a current in a conductor is required, it is proportional to the number of lines or loops around it. If a pull upon an armature is required, it is proportional to the number of lines passing through it as part of the magnetic circuit. It is as simple as ABC if mathematicians and theorists had not thrown an almost impenetrable veil over the matter. The unit of the theorist is unworkable; it is one line through one square centimetre (·155 square inch). Now, in the first place, not one workman in five hundred knows anything about centimetres; and in the second place, the unit is too small, involving figures of abnormal length. And this is how the unit is obtained. Take a coil of one turn of wire, having a diameter of 10 centimetres (3·937in.), and send a current of 7·9578 amperes through it, then at the centre of that coil we get one line through a surface of one square centimetre (·155 square inch). In English workshops, and outside of pedagogic schoolrooms, measurement is made in feet and inches, but the pedagogues throw every possible obstacle in the way of ordinary men knowing what they mean, for the sole purpose, it seems, of making people believe the subject is difficult when in reality it is exceedingly simple, and could, if put properly, be understood by almost every schoolboy in the sixth standard. Examine what this style of measurement means. Take a field of "unit intensity," that is, a field wherein one line passes through every square centimetre (·155 square inch). A square inch equals 6·4514 square centimetres, so that if we, as ordinary men would, reckon in square inches, 6·4514 lines of force or closed curves pass through every square inch section of the field. Take a conductor with dimensions 18in. by 12in., Fig 71. We enclose 18 × 12 × 6·4514 lines or curves of force = 1393·5024, or this number of closed curves passes around the bottom member, B, of the field. To get 1 volt pressure we have to enclose 100,000,000 such curves per second, so the number or revolutions per second must be $\frac{100,000,000}{1393{\cdot}5024 \times 2}$, or over 35,000 revolutions per second.

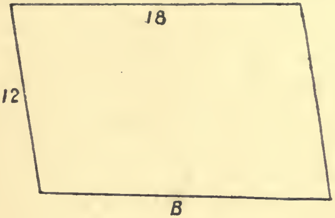


FIG. 71.

Of course, the intensity of the field is always far greater than this, say, 20,000 times—that is, 20,000 lines pass through the square centimetre (·155 square inch). or 20,000 × 6·4514 = 129,028 lines per square inch, The number of revolutions per second to get one volt now becomes only 1·75, reducing the number of revolutions.

If, instead of one turn of wire, we had fifty similar turns, the number of revolutions would be still further reduced.

The reason of multiplying the denominator by 2 in each case is that the top and bottom members of the turn have the loops of force round them in each revolution, and the pressure generated is therefore double of what it would be if only one member per revolution was looped.

These examples show that long numbers, even if the calculations are not difficult, are necessitated by the absurd unit at present in vogue. These remarks apply simply to the unit in the workshop. It serves an admirable purpose in the laboratory. In the conductive circuit there is both a laboratory unit and a practical unit. The "ohm" is the practical unit, and there ought to be a similar practical unit for the magnetic circuit. The best proposal in this direction has come from Mr. Gisbert Kapp, whose practical unit is 6,000 times greater than the one above defined. Therefore, in the above examples, instead of 129,028 lines, in Kapp's units we get $\frac{129{,}028}{6{,}000} =$ 21·5; and according to ordinary methods of thought the figures 21·5 are far easier to manipulate than 129,028. In Mr. Kapp's unit he takes into account, too, the ordinary engineering method of counting revolutions per minute instead of revolutions per second. So far as possible, then, the examples in this book will consider the ordinary ways of working and adopt the Kapp unit. Another step is urgently needed—in the production of sets of magnetic resistances, like sets of conductive resistances. Manufacturers could then take a piece of iron, from the bulk, of certain length and sectional area, wind it with a certain number of ampere-turns, and balance it against a standard resistance, issuing the bulk of iron as having a certain magnetic resistance per unit length and unit section. The magnetic resistance of any length and any section would then be known; for just as with conductors, the resistance varies directly as the length and inversely as the sectional area—that is, double length doubles resistance, double sectional area halves resistance.

The total resistance of any magnetic circuit, just as the total resistance of any conductive circuit, is the sum of the separate resistances. The magnetic resistance of a dynamo generally consists of three parts.

1. The resistance of the core.
2. The resistances of the air spaces between the poles and the armature.
3. The resistance of the armature.

Frequently the core is not a continuous mass of iron, though the resistance would be less if it was, because it is hardly possible to have joints so well made as to give as good conductive continuity as the solid metal. Thus Fig 72, represents a section of the dynamo, C C represent the part of the core around which the coil is wound. Y

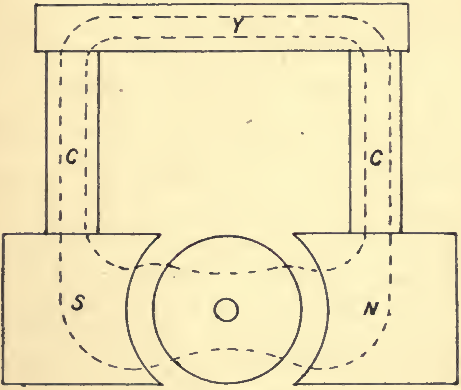


Fig. 72.

represents a yoke joining C C, and should be in good magnetic continuity withC C, as should also the pole-pieces, N S. The lines pass through the air space, through the armature, the other air space, and round the magnet core as shown. The resistance of the whole magnetic circuit then is

$$R = R_1 + R_2 + R_3$$

when R = total resistance; R_1 = resistance of field magnets; R_2 of air spaces; and R_3 of armature.

The aim of every designer of dynamos should be to make R as small as possible.

The second part of the field-magnet we have to consider is the coil. The lines of force in the core are due to the magnetic pressure from the current in the coil, and primarily to the pressure which sets up the current. It has been calculated that one turn of conductor carrying a current of one ampere will exert a magnetic pressure equal to $\frac{4\pi}{10}$. If the current is any other quantity, and is represented by C in amperes, the pressure is $\frac{4\pi C}{10}$, and as every turn in the coil exerts its pressure, the total pressure due to T turns is $\frac{4\pi T C}{10}$. Knowing this, we are in a position to write down the formula for the magnetic circuit, thus:

$$\text{No. of lines of force} = \frac{\text{Pressure}}{\text{Resistance}}$$

$$N = \frac{\frac{4\pi T C}{10}}{R_1 + R_2 + R_3} = \frac{2\pi T C}{5(R_1 + R_2 + R_3)}$$

Now, although one ampere-turn always exerts the same pressure, iron—and this is the metal mostly used—does not always have the same resistance. When the current is first applied the lines of force in iron increase practically in direct proportion to the current, but after a certain number of lines pass through the iron the number

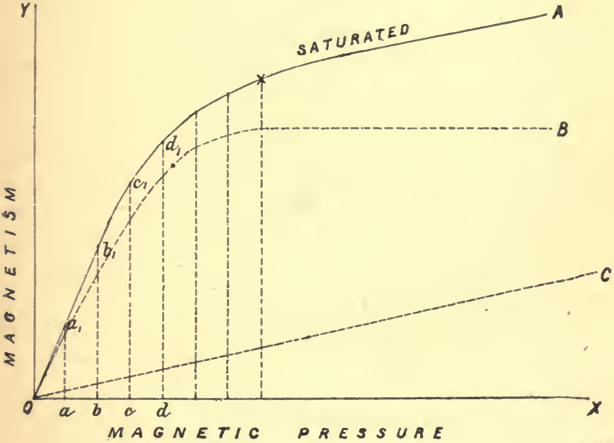


Fig. 73.

does not further increase directly in proportion to the current, and it becomes more and more difficult the further we go to force lines through the iron. This result is well shown by the graphic method. In Fig 73, let O be the origin, O X represent the exciting current, O Y the number of magnetic lines evoked.

The curve O A, which represents the number of lines due to different strengths of current, at first rises almost in a straight line from the origin, then is curved, and subsequently become almost straight again. During the third part the iron is said to have become saturated, the curved part shows the effect of the current when it is partially saturated, and the first straight part shows it before saturation.

In constructing a dynamo it is necessary to be careful to have sufficient iron in the core so that the iron is not over saturated. The point where the iron is saturated, or nearly so, should be that aimed to obtain in the finished machine, because the greatest amount of magnetism is there obtained for the smallest expenditure of iron, wire, or current. If a point much below the saturation point is reached a slight increase or decrease of current leads to proportional fluctuations of magnetic lines, while a point higher up the curve—that is, past the point of saturation—needs a large expenditure of current, for which few lines are obtained. It may here be stated that if the coil has no iron in the core—only a circuit of air—the number of lines is proportional to the magnetic force as shown in the dotted line O C. Undoubtedly the air has its saturation point, but that point will be far outside any ordinary pressure.

Inoperative or Leakage Lines.—If we consider the direction of the lines of force from a coil through an air circuit, the intensity of the lines outside the coil will be sensibly the same in all parts of the external field at equal distances from the exciting wire. The same will hold good for a straight coil and a straight core, because there is no reason why the lines should select one air path more than another, all having the same resistance. Magnetic lines follow the same laws as conductive currents, and divide inversely as the resistances of the circuits. Therefore, although one circuit or branch circuit may be provided which has a much less resistance than any other, only its proportion of magnetic lines will go through this circuit of low resistance. In apparatus such as dynamos it is seen a path of as low resistance as possible is provided, and only the lines going through this circuit are utilised; the remaining lines going through other circuits are wasted, and may therefore be termed leakage lines. In some machines of inferior design leakage is very great, but attention has been paid to this source of loss, and care is now taken in the construction of dynamos to make leakage as small as possible. Thus in Fig 74,

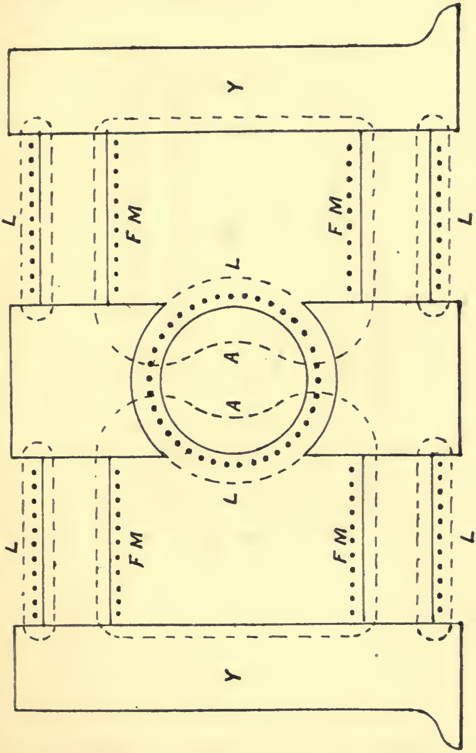


Fig. 74.

the lines represented by L L L L are all waste, only those encircling the wires in armature, A A, being of service. This fact points further to the necessity of making the magnetic resistance, R, as small as possible. Sharp edges and points about the pole-pieces are found to lead to loss by leakage, hence they are carefully avoided. In Fig 74 four coils are used, but in a large number of machines, as in Fig. 72, only two coils are used. Waste lines are frequently found going through the base-plate, thus the

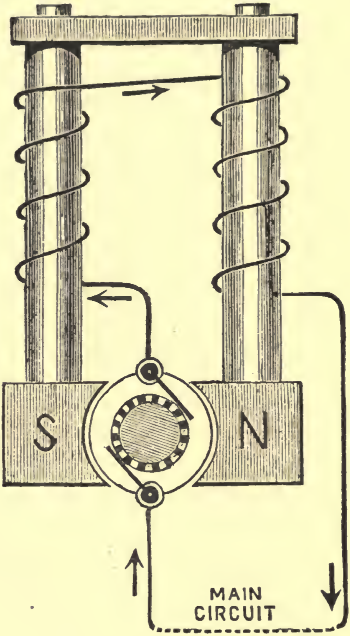


Fig. 75.

pole-pieces are usually kept as far away as possible from all accessory iron and from base-plates. The lines of magnetic force depending only upon the ampere-turns, it does not matter whether the lines are generated by coils of few windings and thick wire, of many windings and fine wire,

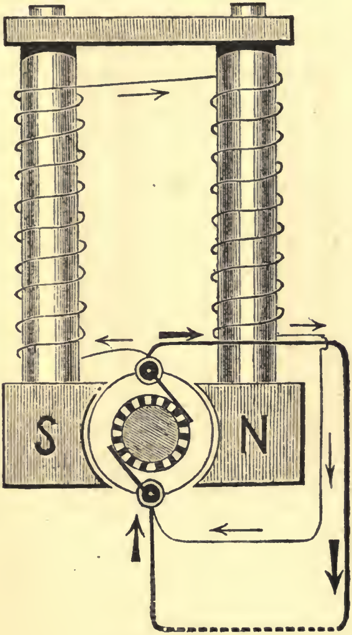


Fig. 76.

or a combination of the two—all that is necessary is that the sum of the products of the current and the number of turns of wire remains the same. When the core is wound with a few windings of thick wire it is generally for what is termed a *series* machine. In these machines the conductor is wound round the armature, then round the field-magnet, and then to the external circuit as shown in Fig 75. In shunt machines, Fig 76, the field-magnets are generally wound with many turns of finer wire, these turns forming a shunt with the external circuit, the current from the machine dividing itself between the shunt coils and the external circuit inversely as their resistances.

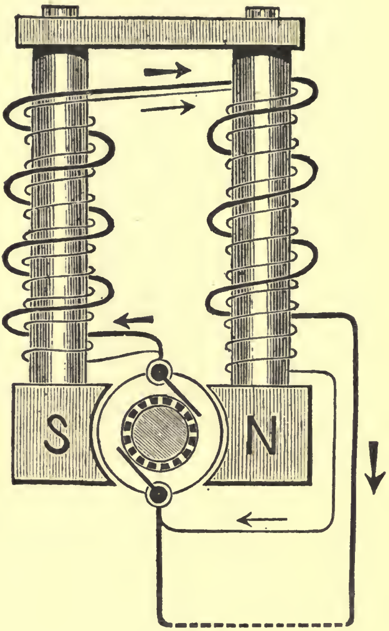


FIG. 77.

Suppose, for example, we require 20,000 ampere-turns, and in the series machine we get them with 1,000 turns and 20 amperes, in the shunt machine we may get them with 5,000 turns and 4 amperes, for 1,000 × 20 = 5,000 × 4. In the third case, or in compound winding, the coils are partly series, and partly shunt wound, Fig. 77. Here we may get the 20,000 ampere- turns by having of the series-turns 300 with 20 amperes, and of the shunt-turns 3,500 with 4 amperes. The total again is :

$$\begin{array}{r} 300 \times 20 = 6{,}000 \\ 3{,}500 \times 4 = 14{,}000 \\ \hline \text{Total, } 20{,}000 \end{array}$$

Temperature of Coil.—The resistance of the conductor increases with rise in temperature. The resistance increases about ·002 for an increase of temperature of 1deg. F., so that to find the resistance due to heating the increased resistance must be added to the normal resistance. For example, a wire that had a resistance of 1 ohm at the temperature measure 50deg. F. would have a resistance of 1 + (·002 × 50) = 1·1 at a temperature of 100deg. F. In the formula below where R is introduced it means the resistance at the temperature under discussion, and not the resistance at the ordinary temperature. The increase of temperature has also a detrimental effect upon the insulation, and if raised too high will soften, perhaps melt and set it on fire. It is necessary then to so arrange the size of wire of the coils and the design of coil that as large a surface as possible, considering all other conditions, may be obtained for heat radiation and convection. This question is perhaps more important when considering the armature coils, but it may be discussed here. The heat generated in a conductor carrying a current is proportional to the product of the square of the current with the resistance

$$C^2 R$$

and the current being continued, expressing time by t this becomes

$$C^2 R t.$$

If the unit of heat taken is that raising 1lb. of water from 0deg. C. to 1deg. C. a current of C amperes through a resistance of R ohms produces per minute $0{\cdot}0315\ C^2R$ units of heat, or generally if H be the number of units in t minutes,

$$H = 0{\cdot}0315\ C^2 R t.$$

Knowing the heat developed it is easy to know the work performed since Joule gave us the mechanical equivalent of heat, which, for the unit adopted, is about 1,400 (1,389·8) foot-pounds. Hence

$$\begin{aligned} \text{Work} &= 1{,}400 \times 0{\cdot}0315\ C^2 R t \\ &= 44{\cdot}25\ C^2 R t. \end{aligned}$$

If all the work done in the circuit is used in producing heat

$$\text{Work} = 44{\cdot}25\ C E t.$$

for $C^2 R t = C C R t$ and $C R = E$.

This applies to all steady currents. In connection with work another unit called the WATT has been adopted.

The WATT (the unit of work) = volt × ampere ($C \times E$) 746 watts = one horse-power.

If in the last formula we require to know the work in horse-power we divide by 33,000, the unit of horse-power—viz., 33,000lb. raised 1 foot in 1 minute. Hence

$$\text{H.P.} = \frac{44{\cdot}25}{33{,}000} C E = \frac{C E}{746}.$$

Taking, then, that the electrical energy = $C E$ or $C^2 R$

developed in any coils is expended in producing heat, then at the point when the temperature remains constant as much heat must be radiated or somehow conveyed away as is produced, or in other words the coil will increase in temperature until the heat dissipated is equal to the heat generated.

In Electrical Engineering if heat is required as for lighting purposes it is required at particular points, and heat developed in the machines or elsewhere in the circuit results in so much waste energy. It is essential that in the dynamos the coils even with continuous running should not heat above a certain maximum or the result may be the melting of the insulation, the fusing of the wire or other damage to the apparatus. Similarly in the conductors used to convey the Electrical energy from one point to another, if these heat above a certain temperature, damage to insulation, and even fires in buildings may result. Mr. Kapp referring to coils for dynamos says:—"if we allow a cooling surface of 2·5 square inches reckoned on the outside of the coil only, for every WATT transformed into heat, the rise of temperature in continuous running will be from 20° to 25° C (36° to 45° F) and this may be taken as a perfectly safe and satisfactory limit" Mr. Esson gives the rise in temperature of coils wound with double-cotton-covered wire, varnished on the exterior as $C^\circ = \frac{W\,55}{S}$ or $F^\circ = \frac{W\,99}{S}$ when C° = degrees Centigrade, F° = degrees Fahrenheit, W is the rate at which energy is dissipated in WATTS and S is the outside cooling surface in square inches. For armatures the surface velocity of which is 50 feet per second, and the exterior diameter of the core 1½ times the interior, the length being about equal to the diameter, this formula with

S = total cooling surface outside, inside and at ends becomes:—

$$C^\circ = \frac{W\ 35}{S} \text{ or } F^\circ = \frac{W\ 45}{S}$$

Mr. Esson gives 30° to 35° C, 54° to 63° F, as the working limit, and 70° to 75° F, as the ultimate limit of rise of temperature under ordinary circumstances and 1·13 sq. in. per WATT cooling surface. Many machines, however, have to run in places where the surrounding temperature is very high, such as in the dynamo rooms on board ship, and then a larger cooling surface is given.

It will be seen that experience has not yet decided the exact surface to be allowed per WATT, but formulæ may be given which will be found useful in practice when the constant adopted is inserted. Let D represent the number of square inches of external surface of coil to be allowed per WATT where the temperature of coil differs from the temperature surrounding the coil by 1° Fahrenheit. The number of WATTS dissipated will increase directly with the temperature the coil may have above that of the surrounding atmosphere—that is if 1 WATT is dissipated by D square inches when the difference of $t = 1^\circ$ F, then 2 WATTS will be dissipated by D square inches when the difference of $t = 2^\circ$ F, and x WATTS will be dissipated by D square inches when the difference of $t = x^\circ$ F.

This may be put another way that the rise of temperature of the coil above that of the atmosphere will be 1° F for every WATT and every D sq. in. of surface.

Let W = WATTS lost in coil; T = temperature in degrees

Fahrenheit, and S = total external surface in square inches—

$$\text{then } W = \frac{T\,S}{D}$$

$$\text{But } W = CE = C^2R = \frac{E^2}{R}$$

values which if inserted in the formula give further information. Thus using the equivalent C E

$$C = \frac{T\,S}{D\,E}$$

which shows the greatest current that may be used in the magnet coils of a shunt machine having a given pressure in order that they do not heat above the allowable temperature.

In a series-wound machine with C known

$$R = \frac{T\,S}{D\,C^2}$$

shows the greatest resistance at the temperature of using that may be given to the coils not to heat too much. The temperature cold is known by allowing for the increase which as has been stated is about ·002 for every degree Fahrenheit.

Or the surface of the coil may be found

$$S = \frac{D\,W}{T}$$

In general, in cheap and badly proportioned machines, the heat limit determines the coil.

Mr. Kapp has given the following investigation of the coil under these circumstances.

The energy wasted must in this case be proportional to the surface of the coil. If we allow a cooling surface of 2½ square inches, reckoned on the outside of the coil only, for every WATT transformed into heat, the rise of temperature in continuous running will be from 20 to 25 deg. C., and this may be taken as a perfectly safe and satisfactory limit. The following symbols will be used :

d......... Diameter of wire in inches.
L......... Length of former in inches.
D...... ... Depth of winding in inches.
R......... Resistance of coil in ohms.
τ......... Number of turns of wire in coil
P......... Perimeter of coil in inches.
W........ Energy lost in WATTS.
X......... Exciting power in ampere-turns.
C......... Current through wire in amperes.

Neglecting for the present all numerical coefficients, we can establish a series of equations between these various quantities. The number of turns in the coil must be proportional to its sectional area, and inversely proportional to the square of the diameter of the wire, or $\tau = \frac{L\,D}{d^2}$.
The resistance is proportional to the perimeter and number of turns, and inversely proportional to the square of the diameter of wire,

$$R = \frac{P\,\tau}{d^2}.$$

The energy lost is proportional to the cooling surface,

$$W = P\,L.$$

It is also proportional to the resistance and square of current,

$$W = R\,C^2.$$

The exciting power is obviously given by the expression,

$$X = \tau\,C.$$

By combining these equations we find

$$P\,L = \frac{P\,\tau}{d^2} C^2$$

$$P\,L = \frac{P\,X^2}{L\,D}$$

$$X = K\,L\,\sqrt{D} \quad . \quad . \quad . \quad (1)$$

Where K is a coefficient depending partly on the size of the wire and partly on the general dimensions of the coil. That this coefficient cannot be a constant is evident from the fact that in the above equation we have taken no account of the ratio between the space wasted by insulation, both of the former and the wire itself, and the space occupied by copper. This ratio is obviously a variable one, the waste being the less, the larger is the whole coil and the stouter the wire. The size of wire has, however, more influence upon K than the general dimensions of the former, and since, in the usual run of designs, the larger coil is generally wound with larger wire, we may determine K merely with regard to the size of wire. In designing a machine we know beforehand, within 15 or 20 per cent., what will be the diameter of the wire to be used for the field, and can therefore hit upon the value of K at once, provided we have determined K for various sizes of wire. To use formula (1) we must therefore have a table giving this value, and it is best to prepare such a table by reference to machines actually built. The table here given has been calculated for a cooling surface of 2·5 square inches per WATT :

Diam. of bare wire in mils.	K.
40	522
120	542
200	570

It will be noticed that the variation in the value of the coefficient is comparatively small, so that a large error in the first guess as to the diameter of the wire to be used only results in a very small error in the final result. Equation (1) gives the exciting power obtainable with a coil L inches long and D inches deep. It can of course, be brought into another form, so as to give the depth or length of coil for any desired exciting power.

The weight of the coil can also be expressed by a general formula, at which we arrive in a way similar to that pursued in arriving at equation (1). It is not necessary to give the method in detail. The result is—

$$\text{Weight in lbs.} = K \frac{P}{L} \left(\frac{X}{1000} \right)^2 \quad . \quad . \quad (2)$$

In this equation K is another coefficient, which must be determined with reference to the gauge of wire used, and the cooling surface allowed per WATT. Where this is 2·5 square inches, we find the following table:

Diam. of bare wire in mils.	K.
40	·495
120	·520
200	·615

It will be seen from equation (1) that an increase in the length of the coil is more effective in augmenting the exciting power than an increase in its thickness, whilst equation (2) shows that the weight is diminished as we increase the length of the coil. It will be understood that the coefficient in (1) is only correct for the ratio of 2·5 square inches of cooling surface per WATT. If a different ratio is adopted, the coefficients must be altered. Let q be the new ratio, then K for this ratio is found by multiplying the value of K given in the table by $\sqrt{\frac{2{\cdot}5}{q}}$ Thus, if the ratio adopted is 5 square inches per WATT, then K for 120 mils. will be $\sqrt{\frac{2{\cdot}5}{5}}542 = \frac{542}{1{\cdot}41} = 384.$

Mr. Kapp also investigated the more general case in which the amount of energy to be wasted in excitation, is settled beforehand. The above formulæ with exception of $W = P\,L$ are used. We thus find, neglecting again all numerical coefficients—

$$W = \frac{P\,\tau\,C^2}{d^2}$$

$$= \frac{P\,\tau^2\,C^2}{L\,D}$$

$$= \frac{P\,X^2}{L\,D}$$

Introducing now a coefficient, K, we have

$$X = K\sqrt{\frac{W\,L\,D}{P}} \quad . \; . \; . \; . \; . \; . \quad (3)$$

In this case, when the loss of energy is fixed beforehand, the exciting power is proportional to the square root of the depth of the coil, as in the other case; but it is also proportional to the square root of the length, and not to the length directly, as in the other case. An increase of length or an increase of depth will therefore be equally efficient. To get a compact design of machine short coils are desirable, and where economy of exciting energy is of first importance such coils can be conveniently used. Where, however, the temperature limit is of first importance, long coils are cheaper than short ones, and then the design of the machine will be less compact, and the iron part of the field will be heavier.

As regards the numerical value of the coefficient K in equation (3), this, of course, also varies with the gauge of wire. The following table gives it between the limits already mentioned:

Diam. of bare wire in mils.	K.
40	820
120	850
200	900

The weight of the coil is proportional to P L D. From (3) we find $X^2 P = W L D$, and multiplying both sides by P we have $X^2 P^2 = W \times \text{weight}$.

Introducing now a coefficient, K, and writing $\frac{X}{1000}$, instead of X, for convenience, we obtain—

$$\text{Weight in pounds} = K \frac{P^2}{W} \left(\frac{X}{1000} \right)^2 \quad . \quad . \quad . \quad . \quad (4)$$

For a constant expenditure of energy the weight increases as the square of the perimeter and as the square of the exciting power. If both perimeter and exciting power remain the same, the weight is inversely as the energy. The coefficient in (4) is as given in the following table:

Diam. of bare wire in mils.	K.
40	·195
120	·205
200	·246

Having by means of these equations found the dimensions and weight of the coil, it is an easy matter to find in the usual way the exact size of wire, turns per layer, number of layers, and resistance, according to the E.M.F. or current available, as the case may be.

Armatures.—The armature of the machine plays a very important part in the economy of the dynamo, and just as there are numerous designs of field-magnets, so there are numerous designs of armatures. This book, dealing solely with elementary principles, cannot attempt to discuss the advantages claimed by one designer for his armature over that of others. There are certain broad principles which must be complied with, and there are certain interactions which must be known. It is these to which we direct attention. For this purpose we must refer again to the interactions between conductors carrying current, between magnetic fields, and between conductive and magnetic fields. Let A B, Fig 78, represent a piece of wire in a circuit carrying current, and the rings represent the "loops of force," the arrows showing the direction of the current and

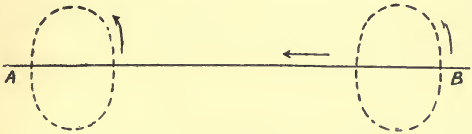


FIG. 78.

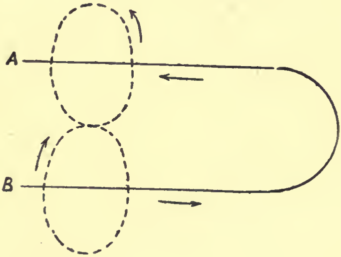


FIG. 79.

the directive action to which the field or "loops of force" are due Further, suppose this part of the circuit bent round on itself as in Fig 79, we then see how the field around one bend of the circuit interacts upon the field around the other bend. The result of this interaction is a partial suppression or seeming partial suppression of the fields and a combination effect, causing a single field to encircle both wires, which may be represented in Fig 80. This mutual action between the wires has the effect also of increasing the resistance of the circuit, thus it will be found that the resistance of a straight length of conductor appears less than the resistance of that same conductor made into a coil. Usually the armature coils are not coils of single turns but coils of many turns, therefore this mutual action of the turns of the same coil has to be allowed for as well as the interactions between the separate coils.

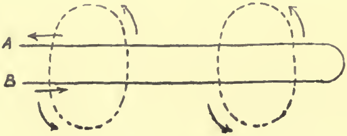


FIG. 80.

It has been stated that the electrical pressure in a circuit under the influence of a magnetic field is due to, and is proportional to, the number of loops around the conductor forming the circuit. Thus the electrical pressure in a circuit of which A B forms part would be proportional to the total number of magnetic loops, and the same holds good if instead of A B being straight it is coiled, though the electrical pressure in the latter case, if there are three coils say, will not cause three times the current in the former, because the resistance has practically been increased by the coiling. It would, however, be inconvenient, if not impossible, to distribute the loops of the magnetic field over long lengths of armature wire, and this little diminution of current owing to greater resistance of coil is easily allowed for in the design.

Consider now, shortly, the air space between the pole-pieces of the field-magnets. Where the space is vacant of everything except air, the magnetic resistance is the sum of the resistances of the field-magnets and the air space. It is clearly of importance to reduce the resistance of the air space as much as possible, and this can only be done by putting into, or bridging over the space, some material, such as iron, which has little magnetic resistance. Iron is therefore largely used, and this introduces other interactions. We have seen that a single or a multiple coil rotated between the field-magnet poles, has generated in it an electrical pressure varying from a minimum to a maximum; and the current due to this pressure is in the case discussed during one half rotation in one direction, and during the other half rotation in the opposite direction. The current, too, varies from a minimum to a maximum under the influence of the pressure. In many operations it is necessary to have the current in the external circuit continuous in one direction. Machines intended to produce such currents are called continuous-current machines, and require an apparatus called a commutator to direct the current always in the direction required. Machines which do not have the current commuted, but sent into the external circuit alternately in opposite directions, are called alternate-current machines. The earlier machines of Faraday and those immediately succeeding him were all of the alternate type.

The commutator arrangement is very simple. In Fig 81, let S represent the spindle upon which the commutator bars are fixed. Strips of brass P P_1 or copper or other suitable conducting material are fixed on the spindles but insulated from it and from each other. The ends of the armature coil A C are connected one end to the bar P, the other end to P_1. Conducting brushes B B_1 rest lightly on P P_1 and are connected to the external circuit E C. As the spindle revolves, the brushes B B_1 are respectively in contact with the commutator bars P P_1. When, however, the spindle has made a half revolution, the brush B comes into contact with bar P_1 and the brush B_1 with bar P. This reversal of brushes compensates for the reversal of current so far as the external circuit is concerned, and the current in the external circuit is always kept in the same direction. Let us trace the path of the current and then the action will appear simple. Suppose the current in the armature coil to commence at P, go in the direction of P_1, pass from P_1 to B_1, and back through B to P, thus com-

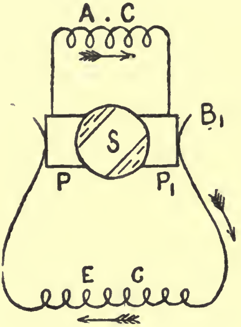


FIG. 81.

pleting the circuit. When the current is reversed in the armature coil as in Fig 82, it goes from P_1 to P, but P is now in contact with B_1 hence the current still goes through B_1 to B and back to P_1. In both cases in the external circuit t goes from B_1 to B, the direction being unaltered.

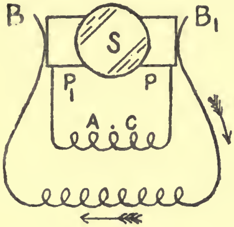


FIG. 82.

In a dynamo there are usually a number of armature coils with a corresponding number of commutator bars. One reason for this we shall now see. It is generally desirable that the current in the external circuit should fluctuate as little as possible, but if only one coil were used it would at each revolution fluctuate considerably. Hence a number of coils are used so arranged as to compensate one another. Suppose A B C D Fig 83, represents the rise and fall of current in one coil. If now another coil in series with number one enters the field at a certain interval after the first one so that A_1 B_1 C_1 D_1 represent its

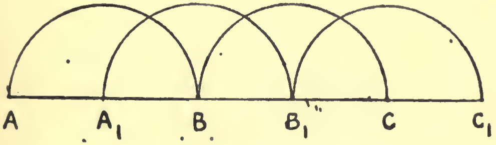


FIG 83

current, the steadiness of the current will be greatly increased and may be represented as in Fig 84. Using a larger number of coils the current can be made so as to show little fluctuation in the external circuit, and the summit of the curves representing it will become almost a straight line.

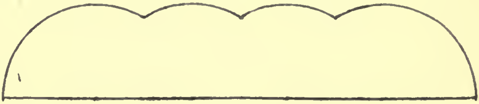


Fig. 84.

In connection with armatures, we shall briefly consider :

1. The main types as shown by their winding.
2. The generation and calculation of the pressure obtained.

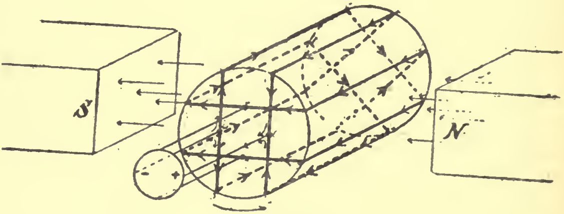


Fig. 85.

3. Some of the interactions of the circuits produced by the action of the armature.

Typical Winding of Armatures.—The armature coils as usually wound are reducible to two types.

1. When the wire of the coil is wound round the core.
2. When the wire of the coil threads the core.

In the first type the armature is generally cylindrical in shape and is termed a drum armature. Fig 85, shows diagrammatically how the windings are made, so that different parts of the armature coil are utilised in different parts of the field to obtain constant pressure, hence constant current in the external field. The core is generally made of discs of soft iron.

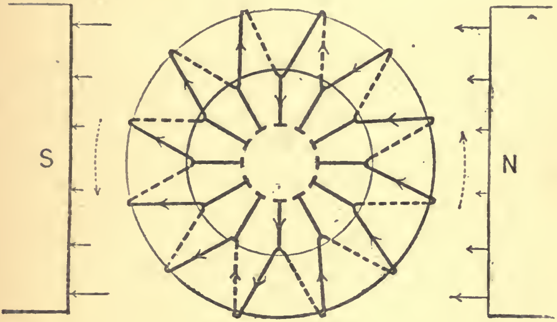


Fig. 86.

This type of armature was devised to lessen the quantity of supposed waste copper in the ring-armature. It will be easily seen that all the wire except that at the ends is threaded or looped by the lines of force. The second, or ring type of armature, is that most frequently adopted for small machines. In this the coils are wound round a ring or core of soft iron as shown in Fig 86. A more detailed examination of the ring shaped armature will assist in making plain the interactions of the conductive and magnetic circuits in this machine. The armature core forms under the action of the armature coils, when there is a current through these coils, a magnetic circuit of comparatively low resistance, and under the action of the current becomes highly magnetised. Now the current in the coils is wanted for other purposes than magnetising the core. Thus in the armature we find a number of interactions.

1. The magnetic loops of the field-magnet circuit encircling the armature coils cause a difference of pressure and generate a current.

2. The current in the armature coils magnetises the core.

3. The iron of the armature core is in the magnetic circuit of the field-magnets. When there is no current in the coils the iron behaves like any other iron in the circuit. When there is current through the coils, the iron belongs as it were to two magnetic circuits, forming indeed the whole or nearly the whole of one magnetic circuit and a smaller part of the other. The interaction between these two magnetic circuits is one of the most important in the armature.

4. The mutual action between the coils due to the current in the coils.

There is one important action connected with number 2 which most writers seem most unaccountedly to have overlooked, though other phenomena connected with this action have received considerable attention. Let a ring armature be represented as in Fig 86. From the nature of the winding two adjacent commutator bars form the ends of one of the coils. In working, care must be taken that the brush which rests upon the commutators does not leave one bar before it touches the next, otherwise a small arc is formed and the brushes and commutators are gradually burned up, besides energy being wasted. If care is taken to do this then the coil which terminates in the two bars thus touched is short circuited. Thus AC Fig 87, may represent this coil, CC_1 the two commutator bars, and B the brush. If under the action of the field-magnets there is a small electrical pressure in the coil there may be a large current in it through the short circuiting. We have seen that the magnetic action of a coil depends upon the ampere turns, and in such a case as this the ampere turns may be very large although the number of turns of wire is small and the pressure is also small. Suppose for example the pressure only ·1 volt and the resistance ·001 ohm, the current would be 100 amperes. This result would have more than one effect. The heat generated, C^2R, might be too great for the wire, and no doubt more than one armature has thus gone wrong. Again the magnetic action developed on the core would be detrimental to the machine because of its adverse interaction with the field of the field-magnet. The remedy is to have no electrical pressure in the coil so short circuited. In the case of the core magnetism then, it must be remembered that in practice both the normal magnetism due to the ordinary current, and, unless prevented, the exceptional magnetism due to such causes as just described, must be considered. It is

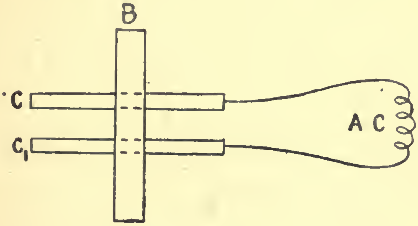


Fig. 87.

impossible in a little book like this to enter fully into the bearing of these phenomena, but it may be pointed out that the armature core forms a part of the field-magnet magnetic circuit. We have seen that as iron becomes magnetised it increases its magnetic resistance. Thus when the armature core is magnetised by the armature coils, its resistance in the magnetic circuit of the field-magnets is increased, and therefore the number of lines of force generated by the ampere turns of the field-magnets is decreased.

These various interactions make the distribution of the field through the armature far from symmetrical.

Pressure in Armature.—We have said that one volt pressure is obtained by looping 100,000,000 lines of force round a conductor per second. In an armature the conductor is wound round the core, so we may speak of a conductor turn, that is, one complete turn around the core, and if 100,000,000 lines of force be looped through one such turn per second, a pressure of one volt is obtained. The pressure is doubled by adding a second turn in series with the first, and looping the same number of lines of force per second around both. It is increased n times by having n turns in series and looping the same number of lines of force per second around each of the n turns. We may symbolise this in the following way:

Let E represent pressure in volts.
n ,, turns of conductor in series.
N ,, number of lines of force looping round each turn,

then $$E = \frac{n\ N}{100{,}000{,}000} = \frac{n\ N}{10^8}$$

If now the conductor turns are revolved in a field of

100,000,000 lines of force, so that the lines of force loop round the turns r times per second, the pressure is increased r times and the formula becomes

$$E = \frac{n\ N\ r}{10^8}$$

The conductor turns of a ring armature form an endless coil closed in itself—that is, it consists of a number of turns—the end of the last turn being joined to the free end of the first, all the turns being in series. The lines of force due to the field-magnets, loop round only a portion of these turns, say n turns, and these turns revolve say r times per second, thus the pressure obtained is indicated by the formula above used:

$$E = \frac{n\ N\ r}{10^8}$$

Let the armature under consideration be that of a Gramme ring, used in a two pole dynamo. Find the number of turns of wire all round the armature: say 100. Call this T. Each turn is looped by the lines of force twice in a revolution of the armature. Thus if there be N lines of force in the magnetic field, each turn of wire is looped by 2 N lines of force per revolution. Usually engineers take revolutions per minute, and dynamos making 1,000 or 1,200 revolutions per minute are quite common. Taking the latter figure this would give 20 revolutions per second. The number of lines of force in the field are numbered by millions. Suppose there are five millions of lines of force looping the armature coils, the pressure is, as usually calculated, said to be due not to the total turns, but to one-half the turns of wire in the armature, for the conductor of the armature is divided at the brushes, Fig 88, into two equal and symmetrical parts in multiple arc with each other. It may be noticed here that the total resistance of the armature is ½ that of either part, or ¼ of what it would be if the whole coils were in series.

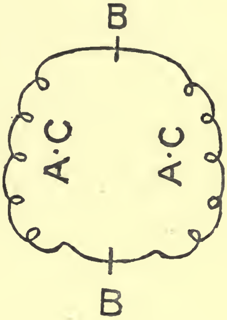


FIG. 88.

Then 1 wire is looped in 1 revolution by 2 N lines of force
T wires are ,, ,, ,, ,, 2 N T ,, ,, ,,
$\frac{T}{2}$,, ,, ,, ,, ,, N T ,, ,, ,,
$\frac{T}{2}$,, ,, ,, ,, r N T ,, ,, ,,

and volts due to $\frac{T}{2}$ wires looped in r revolutions

$$= \frac{r\,N\,T}{100{,}000{,}000.}$$

Putting the figures suggested above in the formula, viz., of a dynamo with 100 turns of wire, making 1,200 revolutions per minute or 20 per second through a uniform magnetic field of 5,000,000 lines of force:

$$\text{volts} = \frac{20 \times 5{,}000{,}000 \times 100}{100{,}000{,}000} = 100$$

$$E = 100 \text{ volts.}$$

We may arrive at this same formula and these same figures in another way. The lines of force from the N poles of the field-magnet on reaching the armature core may be supposed to divide equally, one half traversing the lower half of the armature core, the other half traversing the upper half of the core. The former lines loop the *outside* half of the coil turns upon one half of the armature coils, the latter loop the *inside* half of the wire turns on the other half of the armature. Under this assumption each turn is looped by N lines of force in each revolution. The formula is thus derived:

1 wire is looped during 1 revolution by N lines of force.
T wires are ,, ,, ,, ,, ,, N T ,, ,, ,,
T ,, ,, ,, ,, r ,, ,, r N T ,, ,, ,,

and volts E thus obtained $= \dfrac{r\,N\,T}{100{,}000{,}000} = r\,N\,T\;10^{-8}$

This formula becomes if we use *Kapp* units, letting Z = N, that is Z stands for total number of *Kapp* or English lines lines just as N stands for total number of C G S lines.

$$\textit{Kapp} \text{ units} = \frac{N}{6{,}000}$$

$$\text{and } E = \frac{r\,Z\,T}{1{,}000{,}000} = r\,Z\,T\;10^{-6}$$

Mr. Kapp proposes to call these **English** lines. The English unit line then is 6,000 times greater than the C G S unit line of force.

Density of Lines.—Knowing the total number of lines either C G S or English, it is easy to know the density per square inch where the field is uniform or the average density when it is not uniform. As a rule magnetic fields are not uniform, and it is customary to use density when average density would be more correct. Suppose the section of the armature to be circular, its area A is

$$A = r^2 \pi$$

when r = radius and $\pi = 3{\cdot}1416$.

The lines of force divide between the two halves of the core, therefore the sectional area they traverse $= 2\ r^2\ \pi$. If d = density per square inch and r is measured in inches

$$\text{then } Z = 2\ r^2\ \pi\ d$$

and the formula $r\ Z\ T\ 10^{-6}$ may be written

$$E = 2\, r\, r^2\, \pi\, d\, T\, 10^{-6}$$

The electrical energy developed in the armature when a current C flows through the coils

$$= E\,C = 2\, r\, r^2\, \pi\, d\, T\, 10^{-6}\, C.$$

To express this in horse-power we must divide by 746. Thus we get the horse-power developed in a working armature, and to cause the armature to revolve at the number of revolutions r we shall have to expend more horse power than this, because a certain amount will have been wasted in friction, in churning the air, etc.

The most economical cross section of armature core is that at which the iron is just saturated. According to Kapp, a fair average density is 20 English lines per square inch. The coil is usually laminated so that the whole cross section of the space is not used in conveying lines of force. The waste area must be allowed for in calculations. Mr. Esson gives the limit of density as 17,000 C G S lines per square centimetre, which in English measure is $\frac{17,000}{6,000} \times 6{\cdot}45$ and as 1 square in. = 6·45 square centimetres, this gives about 18 English lines.

It would be nice if the practical questions were all as easily solved as the above, but the various interactions between the circuits introduce all sorts of complications. We will examine a few, but an exhaustive examination would require much greater space and a much wider range of mathematical knowledge than can be given in a small book or expected of its readers.

Some of the interactions among the circuits.— These interactions take place among the following circuits.

1. The magnetic circuit of the field-magnets.
2. The conductive circuit of the armature coils.
3. The magnetic circuit due to the action of the armature conductive circuit upon the armature core.

The first of these circuits has been shown to consist of several parts : the magnet cores, the yoke and the air space. When the armature is in position, a large part of the air space is filled with iron, which reduces the magnetic resistance of the space ; and copper, which has little or no influence upon the magnetic resistance. When the armature is at rest, the lines of force are found somewhat as shown in Fig 89. The lines do not go straight across, but traverse the path of least resistance, which is through the iron of the armature core. They crowd, as it were, into this path of least resistance. Fig 90, shows the lines as indicated by iron filings when the armature is removed. It will be seen that the lines take almost or quite straight lines across from pole to pole. Fig 91, shows the field with the armature inserted, and only a few straggling lines get into the central space. If the armature when running had no influence upon the disposition of the lines of the field, we should expect them to symmetrically divide, as above explained, about the axis of the pole pieces going through the armature core, half traversing the top half of the core, and half traversing the lower half. But this is not found to be the case in practice.

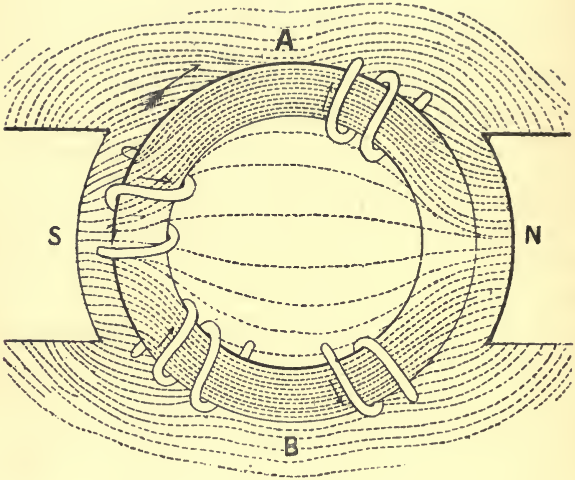


Fig. 89.

There is one vicious error to be corrected here. The word induction has been dragged into every explanation whether required or not. Had the reality of the circuit been accepted years ago, little except the legitimate use would have been made of the term. Once employ a term, and subsequent speakers and writers never seem to stop to think whether it be rightly employed or not, until an iconoclast comes along who is sceptical upon most things till he can see the explanation. The magnetic circuit like the the conductive circuit generally consists of two parts, one part where the lines of force pass through air media or other substance where they can be investigated, the other part going through the interior of the magnetic substance. These may well be called the external and the internal parts of the circuit. It is convention in the conductive circuit to

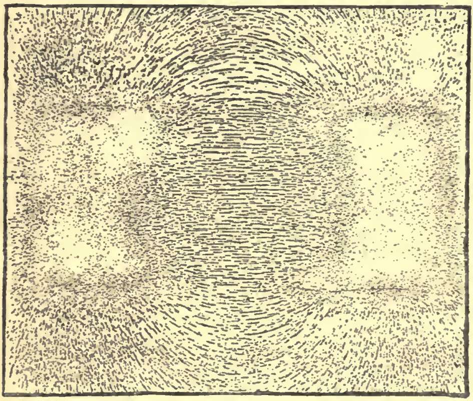


Fig. 90.

say the external current goes from the copper or + pole of the battery through the external circuit to the zinc or − pole, and the internal current from the zinc pole through the liquids of the cell to the copper. A little examination will show the current to be continuous all round the circuit, and nothing but ignorance of the subject in the first place could have warranted so cumbrous a notation.

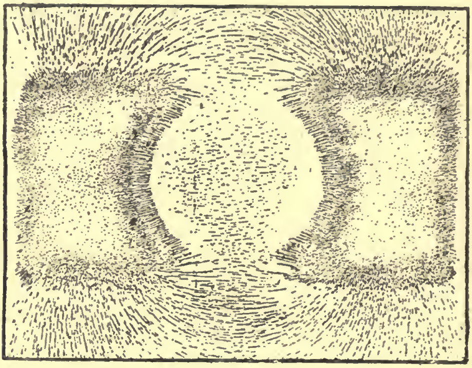


Fig. 91.

If the external conductor of the conductive circuit is made up of various conductors such as silver, copper, iron, etc., we do not say that the current leaving the silver acts inductively upon the copper, or that the current leaving the copper and entering the iron acts inductively upon the iron. Any two points in the external circuit are + and − to each other according to their position. The only question is does the current go *from* one *to* the other. In the internal part of the circuit the notation is reversed though the direction of the current in the circuit is not, and here the points will be – and + to each other according as the current goes *from* one *to* the other.

In the external circuit, then, that point is + from whence the current goes. In the internal circuit that point is – from whence the current goes. This notation is cumbrous, and likely to be misleading and unscientific. The same may be said of the magnetic circuit, only the case is worse. If a bar magnet is divided into two or into ten parts, we get two or ten complete magnets. The convention regarding the lines of force of the magnet is, that in the external part of the circuit they go from the N pole to the S pole, and in the internal part of the circuit they go from the S pole, to the N pole. The direction of action of the lines changes not, it is continuous throughout the circuit. A more scientific convention would be that in the conductive circuit any point is + in regard to another point, if the current goes *from* the first *to* the second, and that in the magnetic circuit any point is N or + to another if the lines of force go *from* the first *to* the second. Any point will consequently be S on to another if the lines of force come *to* that point *from* the other. Of course the existing system had arisen before the magnetic circuit was thought of, and only took into consideration the action of an ordinary compass.

When this matter is considered in connection with a dynamo, explanations are given somewhat as follows. Let Fig 92, represent the apparatus, the N pole of the field magnet is said to induce a S pole in the armature core immediately opposite it, and the S pole of the field-magnet is also said to induce a N pole in the armature core immediately opposite it. Our contention is that these points are points in the circuit and their position decides the polarity of the one to the other. So far as the circuit is concerned, S of the armature opposite to N of the field magnet, is S compared with that point N, but is N compared to the opposite

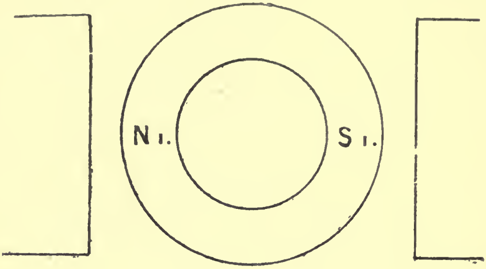


FIG. 92.

pole of the armature core. Our suggestion is merely an extension of the ordinary algebraic convention, that a line drawn from a point in one direction is +, drawn in the other is −. At present if we get a magnetic circuit made up of a series of bits of iron separated by air spaces, we have to reverse our notation at the commencement of every member of the series, though admitting at the same time there is no reversal of the direction of action of the lines of force. We maintain this is cumbrous and unworthy of the scientific tendencies of the day.

Position of Brushes.—If, when the armature is in action, the lines of force in it remained the same as when at rest, S_1 and N_1 would be in the position A B shown in Fig. 89, and the position of the brushes or diameter of commutation would be at right angles to the magnetic axis of the pole pieces. In fact it is at right angles to the magnetic axis, but this axis is moved from its position when the armature is at rest to a new position when there is a current in the armature coils. The current in the coils magnetises the core, and the resultant effect of core magnetism and field magnetism is to alter the direction of the magnetic axis of the field-magnets—that is, the central line about which the magnetic field is symmetrical. The lines of force are crowded towards one corner of each pole piece as shown in Fig. 93, and S_1 is shifted to S_2, and N_1 to N_2. The lines of the brushes or the line of commutation, B_1 B_1, is in the diameter perpendicular to the line S_2 N_2. Fig. 93, supposes the armature to be moving in a direction contrary to that of the hands of a watch. If it be moving in the opposite direction, the magnetic axis will be shifted in the opposite direction. The brushes are then shifted in the direction in which the armature is moving, and this shifting is termed the **lead** of the brushes.

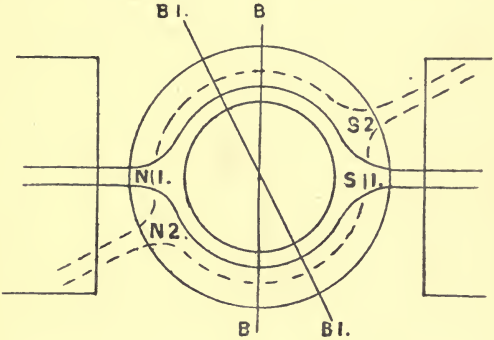


Fig 93.

We have seen that if the brushes leave one commutator bar before touching another, it leads to sparking and the destruction of brushes and commutator. The intensity of this action depends upon the current, that is, upon the pressure and resistance of the coil. Also when the brushes touch two adjacent commutator bars, a coil is short circuited, and a large current may be caused. Now instead short circuiting one coil where the bad effects will be a minimum, many makers adopt the plan of regulating their machines for pressure by moving the brushes from where they ought to be, to positions where they ought not to be, and short circuiting coils which give a worse effect than if the brushes were properly placed. Thus, take an armature with 80 commutator bars, that is, with 40 coils in each half of the armature. Assume, as is usual, that an average pressure is generated in eachcoil through the action of the lines of force looping these 40 coils which are in series, and that this average in each coil produces a pressure of 2·5 volts. The total pressure is $40 \times 2{\cdot}5 = 100$ volts. Now suppose, by moving the brushes, we can arrange to oppose the pressure of one coil to that of the others, we then get a pressure of $39 \times 2{\cdot}5 - 2{\cdot}5$ volts as the total, viz, 95 volts. If the pressure generated in each coil was really the same as we have assumed it, the result would be the same whichever coil was short circuited; but when regulating by opposing a coil or coils to the others, those so opposed may, and often do, have generated in them a greater pressure; hence in the short circuit we get a greater current than at the normal position, hence a greater deteriorating action. Move the brushes of a dynamo running without sparks, you usually get a blaze of fireworks at once. Sparking is bad anyhow, and if such regulation leads to it, then the less it is indulged in the better.

Mechanical disposition of Armature.—Part of the mechanical arrangements of the armature of a dynamo are dictated by electrical reasons, and part are purely mechanical. In the purely mechanical arrangement we have to consider that the armature is made up of various parts, the position of which in relation to each other should be invariable, and that the whole of these parts are to revolve at a more or less high rate of speed. The shaft which carries the armature proper must have a diameter large enough to resist all tendency to bending, and as the shorter it is the less liable to bending, its length cannot be overlooked. On these mechanical points Mr. Hering says: "The bearing at the pulley end should be between the pulley and the armature, and not outside the pulley. The armature and commutator between the two bearings should be as short as possible, and there should be no space lost between them and the bearings. The bearings should be long, at least from three to five times the diameter of the shaft, and should be made of some antifriction metal. In no case should bearings be of iron when the shaft is of iron or steel, on account of the magnetism produced by leakage lines of force increasing the friction. The bearings should be kept free from magnetism; unless this is done, currents are produced through short circuits into the shaft, which may be large, and cause the bearings to heat. The bearings should be bored as true as possible. The supports to the bearings should be as rigid as possible to prevent vibration. In case of high speed it is preferable to allow a slight lateral play to the shaft of from ·25 to ·5 inch, as the oil or other lubricant is better distributed, and the bearings are equally worn instead of being cut and furrowed. The distance between the armature core and the pole pieces should be exactly the same on both sides, otherwise there will be a difference of pull upon the armature tending to bend the shaft and heat the bearings. Again, it is specially necessary with high speeds that the armature be perfectly balanced, otherwise it will vibrate, which tendency to vibration will be increased by the action of the magnetic field. In some cases of want of good balance the armature has come into contact with the pole pieces, the tie bands have been cut, resulting in short circuiting and the destruction of the armature. Great care should be taken in winding the armature to have the outside surface as smooth and as regular as possible, so as to lose as little as possible in friction by churning the air, and of course the armature must be carefully connected to the shaft."

It will be seen that a knowledge of the principles regulating the mechanical disposition of the material built up into an armature necessitates a knowledge of the strength of materials, of the laws relating to motion, and, in fact, a good general knowledge of applied mechanics.

Pull of Field-Magnet upon Armature Core.—If the distance of the core from the field-magnet poles is not the same, the pull is greater upon that side which is nearest the pole. The exact amount of the pull of pole upon pole is still a subject under discussion. Prof. S. Thompson contends that it varies as the "square of the flux." Mr. Hering says: "By reducing the thickness of this space, (air space between pole and core) by one half, it does not follow as is sometimes supposed, that the magnetism will be four times as great, as the well known rule that the magnetic intensity varies inversely as the square of the distance does not apply to the distance between the two neighbouring surfaces of two large magnets." This law of inverse squares holds nowhere in practice, so far as electrical or magnetic apparatus is concerned. Mr. Hering does not investigate what the pull really is, but again all practical men know it is neither "inversely as the square of the distance," nor as "the square of the flux." The subject may perhaps be put upon a sounder footing by a short investigation. We contend the pull to be proportional to the number of lines of force, and if this is so the pull will be more than *doubled* by halving the distance between the acting surfaces, but the exact pull can hardly be given by a simple formula.

Let N be the total number of lines of force acting from N to S, Fig. 94. We have previously stated that the lines of force traverse circuits inversely, as the magnetic resistances of those circuits. If the direct resistance, r, between N S be larger than the indirect or leakage circuit, the proportion of lines from N to S to the total number of lines in the whole circuit may be small, and the number of leakage or inoperative lines may be large. If r_1 is the sum of the leakage resistances, then when $r = r_1$, the number of operative lines = the number of inoperative lines $= \frac{N}{2}$.

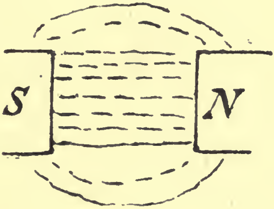


FIG. 94.

The total magnetic resistance is $\frac{r\ r_1}{r + r_1} = R$.

If we halve the distance between N and S and thereby halve the resistance, r, making it $\frac{r}{2}$ the total resistance, R, is not thereby halved, and the number of lines of force is not doubled; that is, N under the new conditions does not become 2 N but, say, M.

If we assume that the sum of the leakage resistance, r_1, has remained the same, so that the ratio of $\frac{r}{2}$ to r_1 is as 1 : 2, then the M lines of force divide,

$\frac{M}{3} \times 2$ lines going through smaller resistance

$\frac{M}{3} \times 1$,, ,, ,, larger resistance.

Under the original assumption $\frac{N}{2}$ lines of force were operative,

Under the new assumption $\frac{2M}{3}$ lines of force are operative,

that is, old pull : new pull : : $\frac{N}{2} : \frac{2M}{3}$;

$$\text{or, } \frac{\text{old pull}}{\text{new pull}} = \frac{\frac{N}{2}}{\frac{2M}{3}} = \frac{3N}{4M}.$$

Even if under new conditions M = 2 N, and this ratio becomes $\frac{3N}{8N}$

it neither bears out the "square of flux" nor "inverse square of distance" theory.

Roughly speaking we may take it that halving the distance between pole and armature increases the pull from two and a half to three times.

CHAPTER IV.

KINDS OF DYNAMO,—CHARACTERISTICS, ETC.

A BRIEF discussion will now be made upon the various types of dynamos in common use, viz.

1. Series wound—Continuous Current.
2. Shunt wound do do
3. Compound wound do do
4. Alternators—or alternate current machines.

One of these will be treated at greater length than the others, because the greater part of what is said will apply to all the machines and need not be repeated.

Series Wound Machines.—In the series wound machines the circuit is continuous from the one brush round the arms of the field-magnet and by the external circuit to the other brush, as shown in Fig 95. Among the more important information required is:

1. The total electromotive force or pressure generated.

2. The working or useful electromotive force or pressure, that is, the difference of pressure between the terminals.

3. The total energy developed by the machines.

4. The useful energy.

5. The difference between the total energy and the useful energy gives that which may be termed waste.

As usual let E = total pressure, and let E_u = useful pressure. Let R = total resistance, and R_a, R_e represent armature resistance—which includes the resistance of armature and field-magnet coils, in fact all internal resistances from terminal to terminal; and external resistance

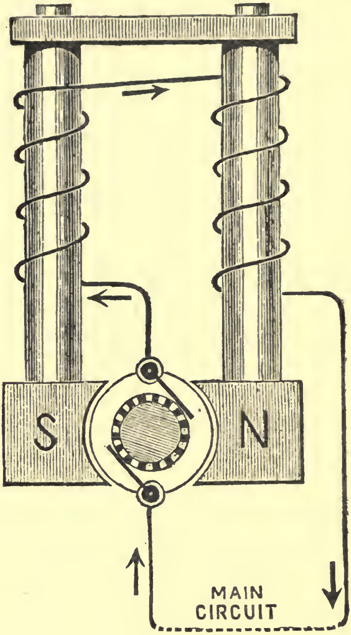


Fig. 95.

respectively. Let P = total energy, P_u = useful energy, and P_w = waste energy.

It is evident that simple applications of Ohm's law give us the information required.

$$\text{Current} = C = \frac{E}{R} = \frac{E}{R_a + R_e}$$

Useful electromotive force or pressure $= E_u$

$$= E - C R_a = C R_e$$

Total energy $P = E C = C^2 R = C^2 (R_a + R_e)$.

Useful energy $P_u = E_u C = C^2 R_e = C^2 (R - R_a)$.

Waste energy $P_w = (E - E_e) C = C^2 R_a = C^2 (R - R_e)$.

The ratio $\frac{P_u}{P} = \frac{E_u}{E} = \frac{R}{R_e} = \frac{R}{R - R_a}$ is easily found.

It will be seen that the formulæ can be given in various ways, and in practice one is more convenient to use than another—which is most convenient depends upon the information to be obtained. Usually in practice it is easy to obtain the useful pressure between the terminals, and the current in the circuit, by the readings on a voltmeter and an ammeter.

It is customary for an engineer to consider above all things the commercial efficiency of his machines. The electrical engineer has to consider the commercial efficiency of a combination of machines. He has a boiler in which to generate steam—an apparatus which may be economical or wasteful; he then has the engine to utilise the steam; he has the driving gear; and finally he gets to the dynamo. From the widest point of view it is wanted to know how much of the energy obtained from the combustion of a pound of coal in the furnace is utilised in the external or working circuit of the dynamo. Taking that every pound of coal consumed in the furnace of the boiler should give 10,000,000 heat units, what part of this energy is obtained in the working cicuit as given by the formula C^2R.

In a narrower sense, and simply to find the efficiency of the dynamo, the engineer compares the energy supplied to the shaft of the dynamo, with the energy obtained in the external circuit, that ratio determines the commercial efficiency of the dynamo. The electrical efficiency is greater, for that will include the energy converted but lost in the armature, etc., that is, in the internal part of the circuit.

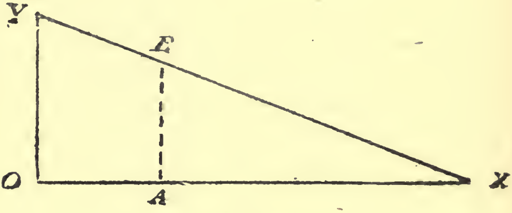


FIG 96.

Suppose x horse power applied to the shaft,

then $\frac{C^2 R}{746}$ is that converted electrically,

and $\frac{C^2 R_e}{746}$ is that converted and utilised.

The best way of dealing with many of these questions is by a graphic representation thus, the available pressure at any point in a circuit is shown in Fig 96, we can represent E by O Y and R by O X, while O A represents R_a and A X represents R_e then A E_u represents E_u or the useful pressure at the point A in the circuit.

Now $E = E_u + C R_a$

and if E is constant, E_u cannot be constant when C changes,

while if E_u is constant, then E cannot be when C changes.

1. With E constant. Let O X, Fig. 97, represent resistance, and O Y pressure. Let O A represent R_a, $A X = R_e$, and $O Y = E$. Join Y X.

Through A draw A E_u parallel to O Y which represents pressure available at terminals.

Through E_u draw $E_u B$ parallel to O X, cutting O Y in B. Then $B Y =$ loss of pressure in internal circuit.

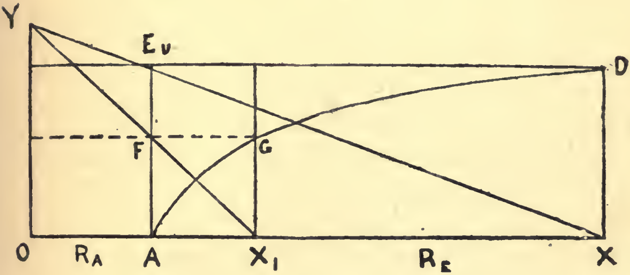


FIG. 97.

Produce B E_u, and through X draw X D parallel to O Y, cutting B E_u produced in D.

Let A X_1 represent a less external resistance.

Join Y X_1. Just as Y X shows the fall of pressure in the above case, so Y X_1 shows the fall of pressure in the new case.

The difference $O Y - A F$ shows the pressure lost, and A F shows the pressure available in the external circuit.

Through X_1 and F draw lines respectively parallel to O Y_1 O X meeting at G.

Similarly taking other resistances less than A X_1 other points can be found, and being joined will give the curve

A G D. This curve shows how the terminal pressure rises when the external resistance is increased from O to A X, The equation to this curve is given by the condition

$$\frac{E - E_u}{E} = \frac{R_a}{R_e - R_a}$$

that is $(E - E_u)(R_e - R_a) = E R_a$.

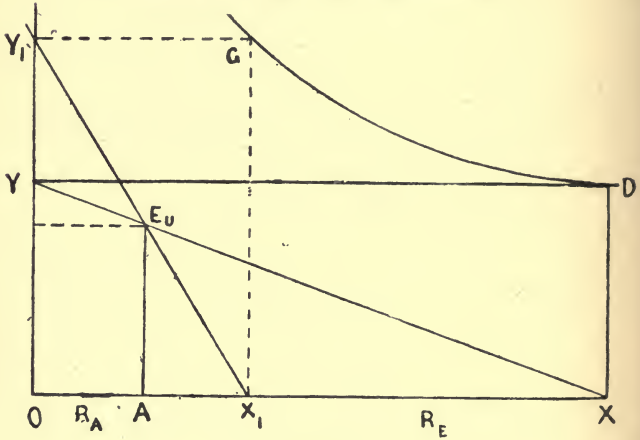


Fig. 98.

2. With E_u constant. Let O X, O A, A X, A E_u Fig 98, represent the resistances R_1 R_a, R_e and the terminal pressure E_u respectively.

Join X E_u and produce X E_u to Y.

Then O Y represents the value of E which will give E_u volts at the the terminals when R_e = A X.

Draw X D parallel and = to O Y.

Take any other external resistance less than A X such as A X_1.

Join X_1 E_u. Produce X_1 E_u to meet O Y produced in Y_1.

From X_1 draw X_1 G parallel and = to O Y_1. Now O_1 Y = X_1 G = value of E when the external resistance is A X_1.

Similarly other points may be obtained for other resistance less than A X and joining the points so obtained we get the curve G D which shows how E must vary to keep E_u constant. The equation to this curve is given by the condition.

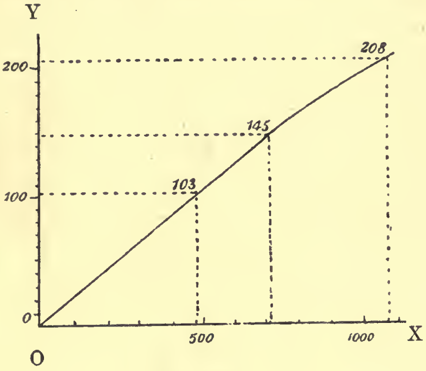


Fig. 99.

$$\frac{E - E_u}{R_a} = \frac{E_u}{R_e}$$

that is $(E - E_u) R_e = E_u R_a$ = constant.

A very slight examination of these diagrams will show that E and E_a approximate to equality when R_e is made larger and larger, so that to find E approximately we have only to make R_e very large and measure the voltage between the terminals.

The Relation between Armature speed and E.—Suppose we take a sheet of square paper, and draw O X Fig. 99, to represent revolutions per minute, and O Y the pressure or electromotive force generated. Ascertaining the value of E for different revolutions and joining these points we get a curve as shown. If the field in which the armature revolved was constant, and the increase of E and therefore of C in the armature had no effect on the interactions between the circuits, the lines would be straight, but these interactions do not remain constant, so the line is slightly curved. According to the curve 500 revolutions give 103 volts, and were there no interactions, 1000 revo-

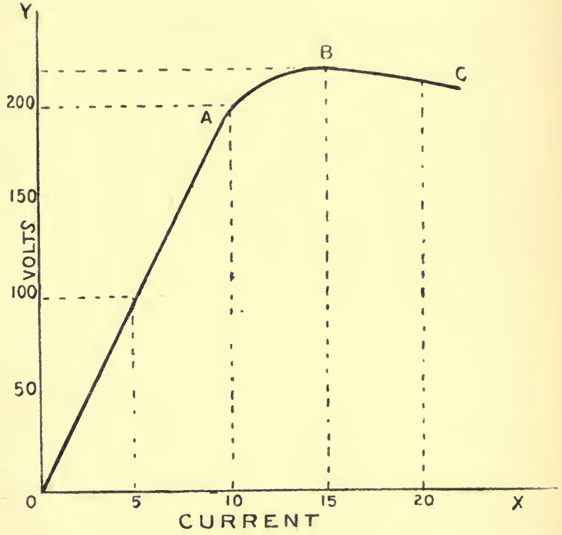


FIG. 100.

lutions would give 206 volts, but 1070 revolutions give only 208 volts, whereas these revolutions should give with no interference of interactious about 222 volts.

Characteristic Curve.—Perhaps the curve which is called the characteristic curve possesses the most importance to the student of dynamos. Let the machine under consideration be a series-wound machine, run at constant speed with a load varying from the largest to the smallest that the machine will carry without injury. Measure for each resistance the difference of pressure or potential at the terminals, and the current. Let the currents be represented along O X, and the pressure along O Y. The intersection of the horizontal and vertical lines which represent the current and the pressure give a series of points, which when joined give the curve called the characteristic of the machine. In Fig. 100, let O A B C represent such a curve, and the interpretation of its peculiarities is the object of the construction. The curve shows tnat when the currents ars small the pressure increases rapidly, and as this part of the curve is almost or quite a straight line the pressure and current increase in the same proportions. When the current has increased to a certain value in the diagram indicated at or about the point A, the pressure increases less rapidly, and soon reaches its maximum limit past which it will probably slightly decrease. Now the practical value of having such a curve as this depends upon the ability to interpret. The complete interpretation can only be understood after a course of study of the dynamo, but sufficient can perhaps be said here to indicate the enormous value of such curves, and to induce the student to closely examine all that may be said about them. The curve given is that known as the external characteristic of a series dynamo. It has already been mentioned that the electrical pressure of the machine increases pretty uniformly according to the number of revolutions. Here we have assumed the revolutions to be constant. Part of the pressure generated is used to overcome the resistance of the armature itself, the remaining part—viz., the difference of pressure or the difference of potential at the terminals of the dynamo—is that available for use in the external circuit. The characteristic curve can take into account the total pressure, or, that available in the external circuit only. From the curve given we should infer, putting other considerations aside, that this machine would not be run to the best advantage if run for pressure or current less than those indicated by point A ; neither should it be run much, if any, beyond point B, as that is the maximum point for pressure. Further, for value of currents between A and C, the machine gives nearly constant pressure for different loads. Of course, the nearer the curve A C is to a straight line the more constant the pressure. If, therefore, it is desired to construct a machine to give a constant pressure, it is necessary to have one that gives a characteristic with A C as nearly a straight line as possible.

How comes there to be such a sharp bend in the curve at A ? Before answering this question let us see how the total characteristic is obtained.

Assume, though of course in an actual case the resistance would be measured, the resistance of the armature to be ·5 ohm.

To drive 5 amperes through ·5 ohm requires 2·5 volts.
,, 10 ,, ,, ·5 ,, ,, 5·0 ,,
20 ,, ,, ·5 ,, ,, 10·0 ,,

From O, Fig 101, draw the line O I at an angle with O X, whose tangent $= \frac{1}{2}$—that is

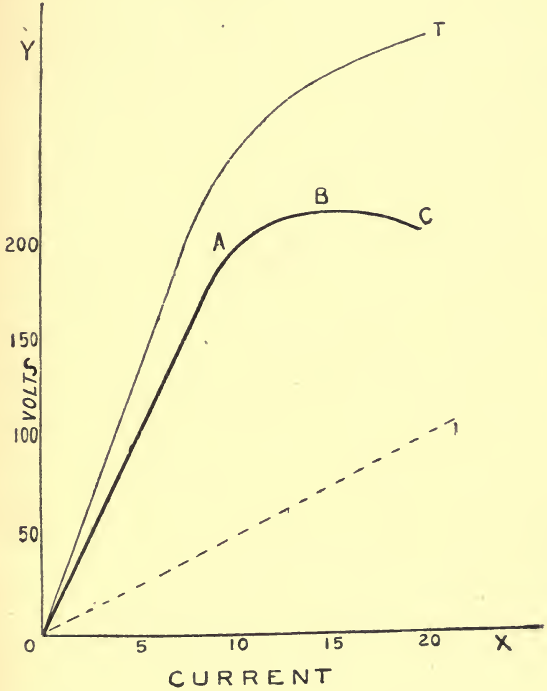


FIG. 101.

$$\frac{\text{numerical value of volts}}{\text{numerical value of amperes}} = \text{in this case } \frac{2{\cdot}5}{5} \text{ or } \frac{5}{10}.$$

The ordinates of this line represent the pressure or electromotive force or volts lost in the armature. Add the ordinates of O I to the corresponding ordinates of O A B C, and we get a series of points which, when connected, give the curve O T. Then the length of ordinates from O X to O T give the total voltage induced, or the curve O T may be called the total characteristic. In practice account must be taken of the rise in temperature causing an increased resistance in the armature, so that the real loss in volts is greater than is depicted in this diagram.

To return to the question, How comes the bend in the curve at A? It has been stated that a current through a coil around a core of soft iron evokes magnetic lines or loops of force. We have seen that

$$\text{Number of loops} = \frac{\text{ampere turns}}{\text{resistance of magnetic circuit}}$$

that is, if the resistance of the magnetic circuit remained constant, the number of loops would vary directly as the ampere-turns, but the resistance is not constant. It increases with the magnetisation, and after a time the sending of additional current through the coil does not increase the number of loops of force through the iron core. When the magnetism of the iron core does not respond to the increase of current, the iron is said to be saturated. In a series-wound machine the magnetic field, in which the armature revolves, increases rapidly in strength till the iron of the field-magnets is saturated. The portion of the curve O A shows the condition while the core is not saturated. An increase of the current in the series coils after A is reached—that is, when the iron is saturated—has little effect in increasing the magnetism, and therefore the pressure.

Just as we have drawn the characteristic between pressure and current, in the same way characteristics may be drawn between the external resistance and the pressure, or between resistance and current, or between the speed and current, or between the speed and pressure. In general, however, characteristics involving changes in speed are less useful, though often very instructive, than the other characteristics, for most engineers consider the question of speed in its relation to the mechanical, rather than the electrical, properties of the machine. The student cannot make himself too familiar with the curves, and should take every possible opportunity of plotting them for himself, and compare the curves taken from one machine with those taken from other similar machines. The characteristics must be drawn or reduced to the same scale before being compared. A characteristic curve can be obtained for any two varying quantities which depend upon each other, and for only two.

Foucault Currents.—If a conductor is brought into a magnetic field, as we have seen a current is obtained. If a conductor is moved about in a field of varied intensity, currents, as it were, ebb and flow in the conductor. A piece of iron is a conductor, hence the core of an armature being a conductor will have currents produced in it when revolved in the magnetic field. The direction of these currents is the same as the useful currents in the copper wire, and obey the same laws. Such currents are not useful, in fact are in the armature core a source of trouble. In order to get rid of them it is usual to laminate the core, that is, make it up of a large number of thin discs insulated from each other. This increases the conductive resistance and reduces the current. As the current is in the same direction as in the copper wire, the lamination of the core must be at right angles to the axis and to the copper wires. One of the evils of not laminating the core is seen if we recollect that $C^2 R$ represents the heating effect of the current, and this heat is not wanted in the armature. These troublesome currents have been called Foucault currents. They could be avoided by making the core of wood or other non-conductor, but we have seen how necessary the iron is in the magnetic circuit, so iron is used, but laminated to reduce the evil to a minimum.

Shunt Wound Dynamos.—In this dynamo the current as it leaves the armature is divided between two circuits. One of these circuits consist of the wire wound round the field-magnets, the other forms the external circuit. We have seen that the magnetic field is due to the ampere turns upon the field-magnet, that is, it depends upon the current through the wire and the number of turns of wire.

In a series machine any alteration in the resistance of the external circuit causes an alteration in the current which goes through the coils of the field-magnet. If the resistance is increased the current is decreased, hence the the ampere turns are lower, and the field is lessened in intensity, so making it more difficult for the armature to generate sufficient pressure to overcome the resistance. Sometimes when the resistance of the circuit is too large, a series machine will not excite, that is, it will not generate pressure and current to energise the field-magnets. It ought to have been stated that there almost always remains a little residual magnetism in the magnets, that is, a few lines of force remain though the machine be at rest and no current round the magnet coils. This residual field, is what first acts upon the revolving armature, and the current thus obtained going through the field-magnet coils increases the field. Another disadvantage of the series machine is that it has an unhappy knack of occasionally reversing its poles, which defect militates against its use in various branches of industry and especially in electro depositing work or in charging accumulators.

Let us examine how the total resistance of the shunt wound machine circuit is obtained.

Let R_a = armature resistance.

R_1 = field-magnet coils resistance.

R_2 = external circuit resistance.

As R_1 and R_2 are in multiple arc, their total resistance is

$$\frac{R_1 R_2}{R_1 + R_2}$$

and the total resistance $R = R_a + \dfrac{R_1 R_2}{R_1 + R_2}$.

The shunt machine is represented in Fig. 102. The current from + brush divides inversely as the resistance R_1 and R_2 represented by the thin and thick lines, and so long as the pressure at the + brush is constant, any alterations of the resistance R_2 will not affect the current in the coils R_1. This may be better understood by reference to a cistern of water in which the water is always kept at the same level. Suppose there are two pipes, A and B to draw water from this cistern. If the tap of pipe A be opened alone, we get a certain quantity of water per second through the pipe, and this quantity will not be perceptibly affected when the tap of pipe B is opened. Each delivers its own constant quantity, provided the level, that is the pressure is constant. If the pipes A and B are equal in all respects they will deliver equal quantities in equal times. So with shunt, branch, or multiple arc circuits in electricity. If the electromotive force or pressure is constant the adding of a second circuit or the alteration of a second circuit makes no perceptible difference to the current in the first. It will be seen, however, from an examination of the characteristic that the armature resistance exerts an influence and has to be considered.

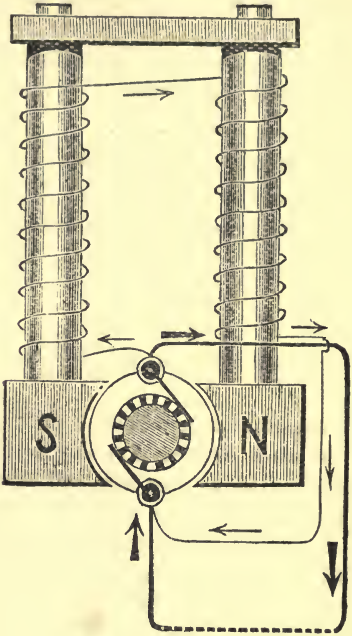


FIG. 102.

To obtain a required field theoretically we have only to consider the product amperes × turns, and resistance of the circuit; but practically, expense and mechanical considerations must be considered. In a series machine the required field is obtained with more amperes and less turns; in a shunt machine we get more turns and less amperes.

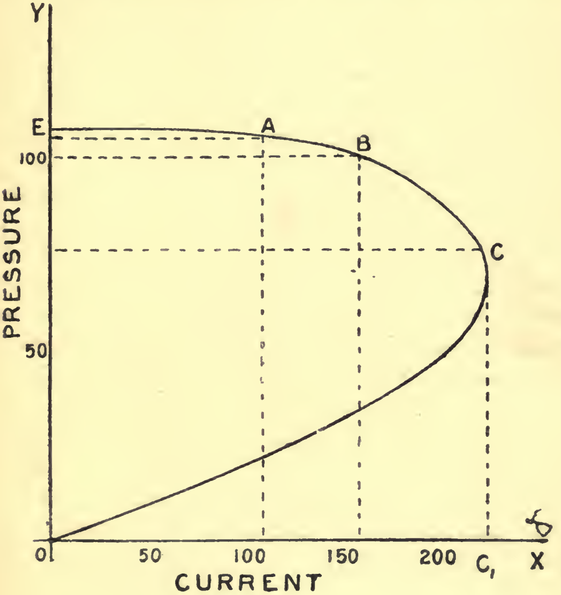


Fig. 103.

Theoretically, ten amperes and two turns are the same as two amperes and ten turns. Less amperes and more turns means greater expense of wire and for labour.

Characteristic of Shunt Dynamo.—The curves which give what may be termed the external characteristic of a shunt machine are altogether different from those of a series machine, though the characteristic of the shunt circuit is similar to that of the external characteristic of a series dynamo. When the external circuit of a shunt machine is open, the whole current goes through the shunt coils, the field-magnets are excited to their highest pitch, and we get maximum pressure. The general external characteristic for current and pressure of a shunt machine with different resistances in the external circuit, is shown in Fig. 103. Let O X represent current, and O Y pressure. Starting with external circuit open the machine gives its maximum pressure O E and no current. Putting a very large resistance between the terminals and gradually reducing it, we get more and more current with pressure falling. It will be seen the first part of the curve E A B C O is almost a straight line, and in this part of the curve the fall of pressure is proportional to the current as the resistance decreases. At A the pressure commences to fall more rapidly, and at B still more rapidly, till at C the maximum current is reached.

If we decrease the resistance past C continuously till the machine is short-circuited, the pressure and the current both fall till, when short-circuited, both are at zero. The curve shows graphically what is known to all after a moment's thought, that maximum pressure is, when all the current goes to excite the field-magnets and no current to the external or working circuit; that when no current goes into the shunt circuit, there is no field, and consequently no pressure and no current. This happens when the machine is short-circuited. The curve shows there is a maximum current = O C_1, and if the armature will stand this maximum current no alteration of the external circuit will injure the machine. In practice, however, no one runs a shunt machine between C and O—

it would be uneconomical. The best machines would be limited to a part of E A B. If any part of E A B was perfectly straight, then the current might be varied at will within the limits of that straight part without alteration of pressure. The inclination of E A B is due to the resistance of the armature, some part of the pressure being used to overcome this resistance. If the armature had no resistance a portion of the curve, say E A, would be horizontal, and then we could have current varying, as mentioned before, with constant pressure.

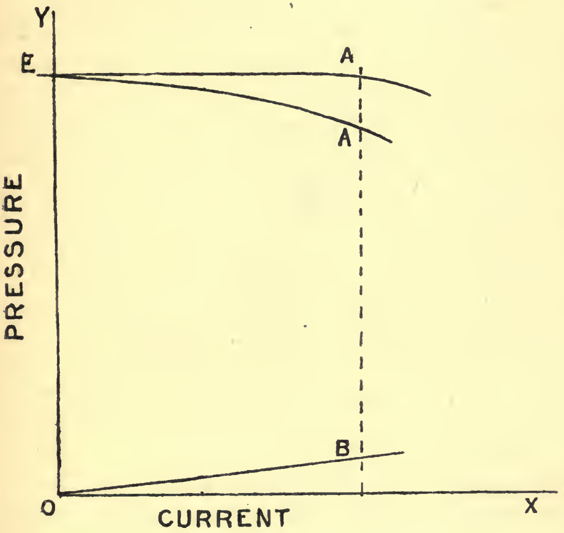


FIG. 104.

The Compound Wound Machine.—An examination of the characteristics of the series and shunt machines shows that in the one case pressure rises, where in the other it falls. It seemed probable then that a combination of the two might keep the pressure constant. The compound machine then, is one that is wound partly in series and partly in shunt, so that the characteristic shall be as straight as possible in that portion which may be termed the working portion. The characteristic of the compound machine will be a combination of the characteristic—the resultant characteristic—of the series and shunt machines. In Fig. 104, let O B represent the rise of pressure due to the series coils, and E A the fall of pressure due to the shunt coils. If O B rises in the exact proportion as E A falls, the pressure will be represented by the straight horizontal line E A, and up to the point where this horizontal line begins to fall the current can vary without variation of pressure. It can be shown that a compound machine should only be used in this straight portion, also that the dropping curve is due principally to saturation, so that we again see that such a machine should not run below the saturation point.

Efficiency.—It is found in practice that so far as small machines are concerned, the ring or Gramme form of armature is efficient, but in large machines and when the length of armature is considerable, these armatures are unsatisfactory. It is often found that the inside coils get very hot while the outside coils are fairly cool. This heat means not only lost energy, but it leads to the heating of the spindle and bearings. A partial remedy is found in blowing cold air through the armature, but such a remedy is unsatisfactory because it means increasing the waste, for however little energy is consumed, some must be—in driving the required air. Hence for this as well as for other reasons the drum or cylinder type of armature is that mostly used for large machines. It may be interesting to the reader to know that a combined efficiency, that is the combined efficiencies of engine and dynamo, of 86 per cent. has been obtained in several instances. Tests with a Willans engine and a Crompton dynamo, also with a Willans engine and a Hopkinson dynamo have both given slightly greater efficiency than this. In such cases it must be taken that the dynamo alone has a commercial efficiency of at least 96 per cent. When, then, we have a piece of apparatus so efficient there does not seem to be room for vital improvements. Further, in trials at the maker's works it should be comparatively easy to obtain one Board of Trade unit, that is 1,000 WATTS, by the consumption of between 4·5 and 5lbs of coal in the furnace of the boiler. To obtain this result, all parts of the combination must be about as perfect as they are made. At the present time then, we may take it that the minimum coal required to provide one Board of Trade unit in the working part of the circuit, is 4·5 lbs. For many reasons this minimum is not approached in practice. In the first place the stoking is far from perfect, many of the boilers that have been adopted in electric lighting are not adapted for the work, worst of all the load upon the engine is far from constant, and great efficiency of dynamo or engine under such conditions is at present unobtainable.

Alternate Current Machines.—Soon after Faraday's discovery in 1831 of the interaction between magnetic and conductive circuits, the apparatus used in the experiments being really the first alternator; such machines were commercially introduced by Pixii, Clarke, and others.

There are certain phenomena more pronounced for good or evil in alternate-current machines than in direct-current, hence these phenomena must now have attention.

Self-Induction or Inductance.—The term is a most unhappy one, but as it is in constant use must be left rather than coin a new one. We have seen that when a current is set up in a wire the observed phenomena are twofold: (1) the internal action; (2) the external action. The latter produces the field around the conductor, and has been conventionally attributed to concentric loops of force. Experiment shows that the full effect of a current in producing a field is not instantaneous, the maximum effect is gradual, and when a current is broken the diminution of effect is also gradual and not instantaneous. We should prefer the number of loops of force around a wire to be taken as the value of the *decrease* of pressure, but using the ordinary notation as marking the value of the increase of pressure the fluctuations of number of lines around any point in a single conductor may be briefly considered.

Let A B be a conductor carrying current from A towards B.

The pressure at A is assumed greater than at B. This pressure may be due to the number of lines of force looped around A, or to the difference in the number looped around A and B.

Let the current due to this difference of pressure be represented by C. If now the pressure at A is decreased so as to be more nearly equal to that at B—which we assume can be done by decreasing the number of lines looping around A—then C will diminish to C_1. The difference between C and C_1, or $C - C_1$, shows the value of the current which would have gone from B to A if both had been at an equal pressure when the pressure at A was reduced. The increase of the lines of force around A tends, therefore, to set up an opposing current to the original current. Similarly, the decrease of the lines of force will tend to set up a current in the same direction as the original one. The action of these currents is but momentary, but it prevents any change of pressure exercising an instantaneous effect. This action is termed "self-induction." The disadvantage of self-induction is generally seen when breaking the circuit, the momentary pressure generated by the collapse of the lines of force being often much greater than that which maintains the current. The effect of self-induction in a single straight wire is comparatively small to that in coils, and especially to that in coils with iron cores. When wire is wound in coils there seems to be a partial suppression of lines; but in the collapse the whole value of these suppressed lines is added to the momentary effect, hence there should be no difficulty in seeing how it is that the pressure of self-induction may be so much greater than the maintaining pressure. This great pressure is frequently the means of breaking down insulation, and damaging apparatus that would not be injured by ordinary pressure. The action of self-induction hinders any sudden changes of current in the circuit, so that in circuits with much self-induction these sudden changes are impossible. The effect of self-induction in alternators is to retard the current getting to its maximum strength; it is as if a resistance were added which the pressure takes time to overcome.

Coefficient of Self Induction.—This is symbolised by L and is equal to the number of lines of force embraced by the circuit uninfluenced by any other circuit, and carrying unit current. The whole self-induction in a circuit with C units of current is L C. Some authors define L as equal to half the number of lines as above, but it seems better to call $\frac{L\,C}{2}$ the *average* self-induction.

Ideal Alternator.—If we take one complete coil of wire, Fig 105, and revolve it between the field-magnet

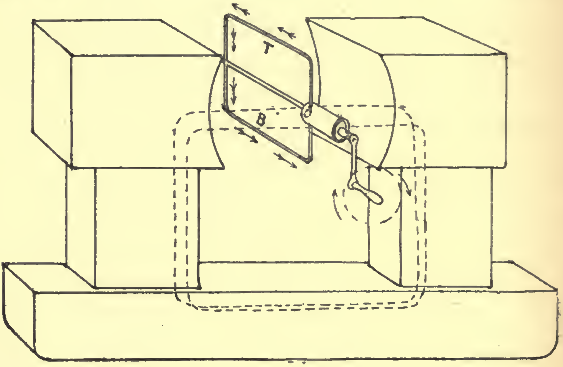


FIG. 105.

poles, the whole of the loops of force in the area of the coil are looped around each half of the coil twice during a complete revolution, and the current likewise has its direction changed twice during the revolution. Suppose the field uniform, then the number of loops around either half of the coil will depend upon the position of the coil. When vertical as in the figure, all the loops pass around B and none around T, so that passing from the position B to the position T, the pressure and the current going from a maximum to a minimum, are then reversed, and similar action but of opposite sign takes place in the other half revolution. The working machine generally consists of a number of field-magnet poles and armatures. In some cases the field-magnets revolve, in others the armature revolves. In the Gordon machine the field-magnets revolve. In one of his machines he has thirty two armature co carried by a wrought iron wheel. As the field-magnet poles pass the soft iron poles of the fixed coils, the magnetic loops encircle the coils. The consecutive field-magnet poles are of opposite polarity, so that the current in the coil is reversed at each successive magnet pole, or 32 times in each revolution. There are about 150 revolutions per minute, so that the number of reversals per minute is 32 × 150 = 4,800, This is but a moderate total, some makers going to three or four times this number.

Variation of Pressure in Coil.—A previous investigation has shown that the pressure obtained depends upon the number of lines of force per second looped round the conductor. It is easy to show that the number of lines looping the wires of the coil varies with the position of the coil, being fewest, practically none, when the coil is parallel with the lines, and largest when at right angles to the lines. We assume the field to be uniform. When the rectangular coil is in the position A B, Fig. 106, the greatest number of lines are enclosed, when in the position C D the least number. Suppose the coil to be in a position E F, making the angle E O C between E O O C. If E F is projected upon A B the projected line cuts off a part G H.

Whatever be the ratio between G H and A B this will give the ratio between the number of lines looped in the new position to the maximum number looped.

But the ratio of G H to A B is the same as the ratio

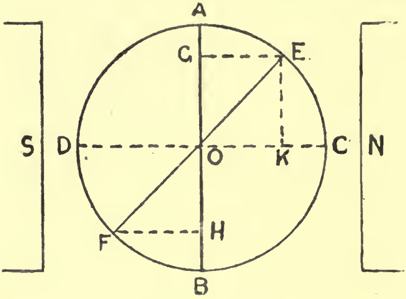


FIG. 106.

$\frac{GH}{2}$ to $\frac{AB}{2}$, that is, as G O to A O.

But G O = E K.

And A O = E O.

$$\text{therefore } \frac{GO}{AO} = \frac{GO}{EO} = \text{Cos. EOA} = \text{Sin. EOC}$$

$$\text{for } EOC = 90^\circ - EOA.$$

This shows that the number of lines enclosed will vary as the sine of the angle between the line showing position of the coil when parallel with the lines of force, and the position at the moment; or it varies as the cosine of the angle between the line of maximum force, and the line of the position at the moment.

The pressure is determined by the number of lines looped per second, and for simplicity we consider the half loop B shown in Fig. 105, rectangular in shape.

Let F = intensity of lines per unit area.

l = length of loop,

b = breadth of loop,

then area of loop = l b,

and number of lines in l b = F l b.

The loop encloses this number of lines twice in a revolution,

therefore if N is total number enclosed per revolution,

$$N = 2\,F\,l\,b.$$

If the loop makes r revolutions per second,

total number of lines looped per second = $2\,r\,F\,l\,b$

therefore $E = 2\,r\,F\,l\,b$

or in volts $E = \frac{2\,r\,F\,l\,b}{10^8}$

Put N for 2 F l b and this becomes

$$E = \frac{r\ N}{10^8},\ \text{in English measure}\ E = \frac{r\ Z}{10^6}$$

With T loops instead of the one

we get $E = \frac{r\ N\ T}{10^8}$, in English measure $E = \frac{r\ Z\ T}{10^6}$

If instead of one reversal per revolution, or a frequency of one, the frequency is n per second—that is, n complete periods per second—then

$$E = \frac{r\ n\ N\ T}{10^8}\ \text{or}\ \frac{r\ n\ Z\ T}{10^6}$$

The pressure at any moment will depend upon the position of the loop—that is, upon the angle α—and this is found by

$$E = \frac{r\ n\ N\ T}{10^8}\ \text{Sin.}\ \alpha,\ \text{or}\ E = \frac{r\ n\ Z\ T}{10^6}\ \text{Sin.}\ \alpha$$

It can be shown that the *average* pressure or electromotive force will be

$$E = 2\,r\,Z\,T$$

when T represents the number of turns of wire forming the rectangular coil, the turns being wound and counted on both sides and insulated from each other—that is, the electromotive forces in both branches of the coil are added.

As the armature of continuous-current machines is in multiple arc, similar machines containing the same materials, wound—one for alternate current, the other for continuous—would differ, in that the pressure in the former would be theoretically more than double that of the latter, while the current in the armature of the latter would be double of the former with same density in each armature; so that the output of the alternator would not be theoretically greatly in excess of the continuous-current machine—(about 12 per cent. according to Mr. Kapp).

An alternator requires a separate machine to excite its field-magnets; and here again it differs from the continuous-current machines, the field-magnets of which are excited by currents from their own armatures.

Transformers.—The main reason for employing alternators in industrial operations is that the distribution of electrical energy under high pressure is more economical when long distances are concerned, than is distribution under low pressure. In the use of the high pressure system, means have to be adopted at the points of using the energy, to transform the dangerous high pressure to safer low pressure. In other words, the energy is conveyed over long distances at high pressure because of cheapness. The pressure is reduced to the working limit at the necessary points by means of "transformers." This name is given to an apparatus which is really but a modified dynamo, perhaps it would be better to say a modified alternator; in fact it is the simplest form of alternator, and in a measure, the most efficient. In the alternator with fixed armature and moving field, the lines of force of the successive fields are looped round the armature coils. There is no necessity to revolve either field-magnets or armatures, for if both are stationary, as in the transformer, and properly placed, the making or breaking of the current from the generating machine gives us alternate currents in the working circuit of the transformer. To obtain a satisfactory result, the resistance of the magnetic circuit of the transformer must be very small. Faraday's original transformer consisted of an iron ring upon which was wound two coils of wire, Fig 107, A called the primary, and B called the secondary coil. Faraday found that on sending a current through the coil A, he obtained a momentary current in coil B, and on breaking the current of coil A, he got a momentary current, but reversed in direction to the previous current in the coil B.

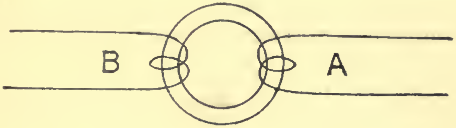


Fig. 107.

We have shown:

1. That a current in a coil around a closed iron core generates magnetic lines; by far the greater number of lines

pass—we may assume for simplicity that all pass—around the core, because of its small magnetic resistance.

2. That the electrical pressure generated in a conductor is due to the number of magnetic loops encircled around it per second.

3. That the current in B is but momentary, and appears only where the current in A is made, broken or varied.

If the current in A be that obtained from an alternator, it varies from a minimum to a maximum, back again, then changes sign and varies similarly through that sign to the starting point.

The current in A being thus varied, the current in B will be similarly varied, but will always be opposite in sign to that in A.

It is easy to see why this should be so. The number of lines due to the action of the current through A will vary as the current, increase and decrease with it, change sign, increase and decrease again just as the current does, and these lines loop the coils of B, causing the pressure and current therein when the circuit is closed.

A little consideration will show that as the currents in A and B are of opposite sign, the tendency of the current in B will be to magnetise the core oppositely to the magnetism due to A. The total or resultant magnetising force is $\frac{4\pi\ (T_a C_a + T_b C_b)}{10}$ where the proper signs + or − must be given to the currents C_a and C_b. This opposition magnetism is greatest when the secondary circuit is doing full work, because then the difference of phase in the opposite currents is least, that is, the current of opposite sign in the secondary is almost at its maximum when the current in the primary is at its maximum.

In order to know the interactions, we must first know the current in A; also the number of turns of wire around the core of A.

We know that No. of ines of force $= \frac{\text{ampere turns}}{\text{magnetic resistance}} = \frac{4 \pi \text{T C}}{10 \text{R}}$ and that the pressure in B is due to the number of turns of B, and the number of lines per second looping these turns.

Modern Transformers are Improvements upon Faraday's. As a rule the primary and secondary circuits are wound one on the other around the same core. It will be gathered that the transformer must be so designed hat the core at any rate is not saturated at anything under the maximum current in the primary. Nor must the heating effect be neglected. In fact the question of heat almost or quite decides the whole question of design. We have said the duty of the transformer is to change a small current of high pressure to a larger current at low pressure. Thus a current of 1 ampere at 10,000 volts sent through a transformer having 20 times as many turns on its primary as on its secondary, will be transformed to 20 amperes at 500 volts. A frequent transformation is from a main current at 2,000 volts, to a working current at 100 volts. Mr. Ferranti, however, proposes to have a main current at 10,000 volts and to transform this down twice, the first time to 2,000 volts and then to 100 volts.

Motors.—By far the most important work in electrical engineering is that connected with the transmission of power, though at present it is almost a virgin field. It has long been known that a dynamo is a reversible machine, that is, when rotating the armature in a magnetic field by applying mechanical energy, we obtain electrical energy from the armature; on the other hand, by applying electrical energy to the armature in a magnetic field, we cause it to rotate and so obtain mechanical energy. This applies more especially to the direct current dynamo, and many types are made to be used only as motors. The alternator is also reversible, but at present has not been brought to the same perfection, nor used to the same extent as the continuous current motor.

Referring once more to Fig. 105, instead of rotating the coil in a uniform field let us suppose a current sent through the coil, and for simplicity the magnet-field to be excited from a separate source. In the former case that length of coil was active which was looped by lines of force, and the same length of coil will in the case just supposed, be active in the interactions between the conductive and the magnetic circuits. We have shown that the two fields can only be brought into the same space by an expenditure of energy, and that there is a seeming repulsion when one field is brought within the influence of the other, or if in the field, ~~can only be kept there by an expenditure of~~ energy. The mechanical force W that would be necessary to keep the conductor stationary in the field when the conductor is at right angles to the lines of force of the field can be shown to be equal to the product of the length of conductor, the current in the conductor and the intensity of the lines of force of the field looping the conductor per unit length.

If L = length of conductor, C = current, and I = intensity of field, then $W = I\,C\,L$.

From this it may be gathered that the greatest turning moment of a motor, the statical moment or as it is called *torque* is when it has the greatest current through the coils. This is when it is at rest, and is in many cases just the time when it is wanted. A motor driving a tram-car, or a piece of machinery requires to exert a greater pull at the moment of starting to overcome inertia than when the car or machinery is in motion. Few motors are constructed, however, to carry so large current during more than a very short period of time.

The length of active conductor in a motor armature similar to a Gramme ring may be taken as equal to the length of the armature multiplied by the number of turns of wire all round. This is not quite exact because the field-magnet lines loop the outside wires in one half the armature and the inside coils in the other half. The wire in the turns at the ends being more or less inactive and useful only as conductively connecting the various lengths of active wire.

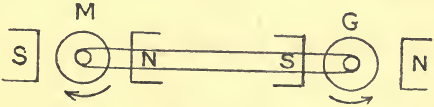


FIG. 108.

If the conductor be allowed to move it will rotate in the field in such a direction as under the action of the field there will be generated in the conductor a pressure or electro-motive force in opposition to the pressure which causes the original current in the coil. Instead of a single coil the armature coils consist of a number of turns, increasing the length of conductor acted upon, and thus increasing the action.

Let G and M Fig. 108, represent generating dynamo and motor. When the armature of G is revolved at a constant speed in a constant field a certain pressure E is obtained.

This causes a current to flow through the circuit, which we suppose to consist of the connecting wires and the armature of M. When the current from G passes through the armature of M, that armature revolves in a direction opposite to the direction of the revolution of G, and this generates a pressure E, which, as it were, is a pressure acting in opposition to e. This pressure is frequently termed the counter electromotive force or counter pressure, and the efficiency of the motor is known by the ratio of e to E.

$$\text{Efficiency of motor} = \frac{\text{counter-electromotive force}}{\text{generator-electromotive force}} = \frac{e}{E}$$

for we know that the energy of a circuit $W = C\,E$ or $\frac{E^2}{R}$

$$\text{If } W = \text{energy due to generator } W = \frac{E^2}{R}$$

$$w = \quad ,, \quad ,, \quad ,, \quad \text{motor} \quad w = \frac{e^2}{R}$$

$$\text{whence } w : W : : e : E \text{ or } \frac{w}{W} = \frac{e}{E}$$

The efficiency might just as well be expressed in terms of the current, for, taking the resistance as constant, the current through the armature at rest will bear the same proportion to the current which would result from the counter pressure as the main pressure does to the counter pressure, Thus if C = current through R due to e : and C = current through R due to E.

$$\text{then } c = e\,R$$

$$\text{and } C = E\,R$$

$$\text{whence } \frac{c}{C} = \frac{e}{E} = \frac{w}{W}$$

The efficiency of a motor may therefore be as large as we please. Till recently many writers confounded efficiency with maximum rate of doing work. The latter obtains when the counter pressure is one half the main pressure, which means that the efficiency of a motor is only 50 per cent when it does its work at the maximum rate. To get greater efficiency, then, its work must be done more slowly.

CHAPTER V.

DISTRIBUTION.

When the electrical energy has been obtained at the terminals of the dynamo or alternator, it has to be conducted to the point or points where it is to be utilised. This may be done in a variety of ways :

1. It may be sent direct into a series circuit.

2. It may be sent direct into a multiple arc circuit.

(1, & 2. A modification of one and two, is the multiple series system.)

3. It may be sent direct into a circuit on the three wire system.

4. It may be sent direct into a net-work circuit and so to supply light or energy.

5. It may be used to produce chemical action in secondary batteries and subsequently this chemical action be reversed to give back the electrical energy.

6. It may be used by means of a high pressure system and transformers.

7. The transformers may be sparsely used to transform for whole districts or may be used in every house, etc. etc.

So far as the conductors are concerned however, they are ultimately reducible to one or other of the first four.

Series Circuit. This is perhaps the simplest case. The external circuit consists of only one conductor, or conductors in series, as in Fig 109, when D represents the dynamo and LL represents lamps. The total resistance of the circuit is necessarily large and therefore the pressure produced by the dynamo must be large.

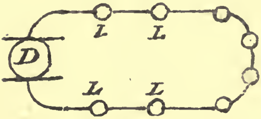


Fig. 109.

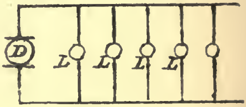


Fig. 110.

One great objection to this method is that any alteration in resistance to one part of the circuit affects the whole circuit, and an accidental breaking of the circuit means complete stoppage of the current throughout.

Parallel Circuit.—The introduction of incandescent lamps into electric lighting necessitated the use of the parallel system, for while it was possible and practical to arrange for the continuance of current through the other arc lamps in a series circuit when one went wrong, it was not practicable to so arrange with incandescent lamps. Hence arose the arrangement as in Fig 110. This arrangement means a low external resistance, and therefore requires dynamos of a different kind to those for use with a series circuit. But in large installations, where incandescent lamps are mostly used, neither of these primitive methods are adopted. Werderman first suggested and Brush subsequently used the multiple series method which may be illustrated as in Figs. 111-112. The calculations to find the total resistance of the circuits of either of these methods have been given in previous chapters.

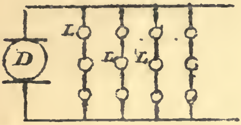


Fig. 111.

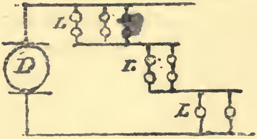


Fig. 112.

Dr. Hopkinson on this side the Atlantic, and Mr Edison on the other, about the same time suggested a modification of the simple parallel system, for the express purpose of saving a part of the copper in the conductors. This is termed the three wire system, and a fairly complete exposition of this system, with what has been said previously about

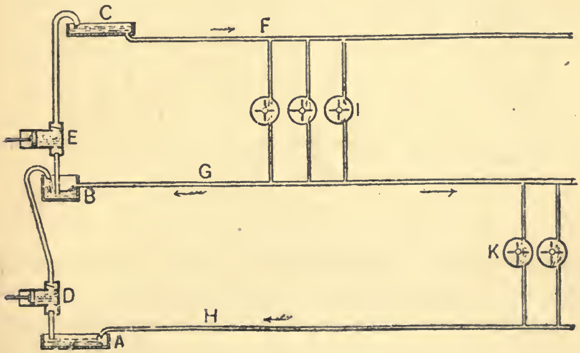


Fig. 113.

"series" and "parallel" systems will enable the student to understand most of the practice of to-day.

Three Wire System.—Let A. Fig. 113, represent a reservoir of water, D a pump, B a second reservoir, E a pump, C another reservoir, F, G, H, channels or pipes to water wheels. Suppose D lifts water from A to B, say 10 feet, and E from B to C, also 10 feet, each wheel is operated by water having the same head or pressure. If the wheels are arranged as in Fig. 113, the discharge from C through the three wheels by F partly finds its way by the channel G by the two wheels at K, and partly back to the reservoir B. It is the difference used by 3 wheels and by 2 wheels that finds its way back by G to B. The arrows show the direction of the flow. In Fig. 114, where the number of wheels is reversed, G still carries the difference, though the wheels are differently arranged. A slight examination of these diagrams also shows that in the first case the pump E has to do more work than D; in the

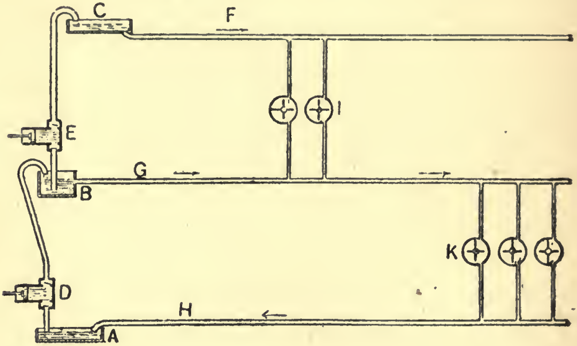


Fig. 114.

second case D does more work than E, The analogy between water and electricity is by no means perfect. It is used only to show that the flow to or from B is usually a difference, and not equal to the flow to or from A and C.

Suppose we have two dynamos A and B Fig. 115, coupled in series, that is the + terminal of one dynamo to the – terminal of the other, the other terminals of the dynamos

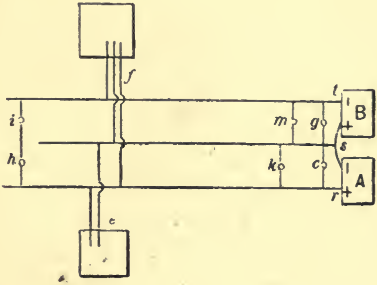


FIG. 115.

being connected to the line wires Now run a third wire from any point on the conductor *s* connecting the dynamos. The positive terminal of the combination is at *r*, the negative at *t*, the third wire being + to A and – to B. If the ordinary pressure of A = 100 volts and of B – 100 volts, then the combined pressure = 200 volts r the difference of pressure between *r* and *t* = 200 volts ut the difference of pressure between either of the mains and the third wire is still 100 volts, just enough for the 100 volt lamp. If such a lamp is inserted at *c*, then the dynamo A will be doing work, and the return current is through *s* to the terminal. If the lamp *g* is inserted, then

B does work. If both *c* and *g* be inserted, or *k* and *m*, or *h* and *i*, then the double pressure acts as if there were no third wire. So long as the number of lamps on the one side is the same as the number on the other, the third wire does not come into play and we may look upon the lamps as arranged in multiple series. If, however, the number of lamps on one side exceeds that on the other, a current will flow through the third wire to or from the machine carrying the heavier load. This current, then, is a difference, just as the water flow was a difference. If now instead of two dynamos in series—each, however, feeding lamps at its own pressure—we had two dynamos feeding two separate circuits, four wires would be required instead of the three as here shown, and each of these four wires would have to carry the full current. Again the current would be smaller with the higher pressure, so that smaller conductors can be used for the mains on the three wire system than can be used on the separate parallel system. For suppose in the parallel system we have lamps of 100 ohms resistance at *c* and *k*

The joint resistance is $\frac{100}{2} = 50$ ohms, and

$$C = \frac{E}{R} = \frac{100}{50} = 2.$$

That is, the dynamo A supplies a current of 2 amperes through this resistance of ~~two ohms~~. 50 ohms

Now suppose on the three wire system these two lamps are put at *c* and *g*. The resistance of the circuit is $100 + 100 = 200$ ohms, and

$$C = \frac{E}{R} = \frac{200}{200} = 1.$$

That is, the dynamos A and B supply current of 1 ampere through this resistance of 200 ohms.

We might have taken any other number of lamps, say 100 in each case.

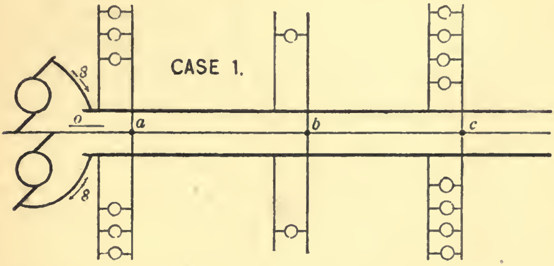


Fig. 116.

Then in the first or parallel system, $R = \frac{100}{100} = 1$ ohm,

$$\text{and } C = \frac{E}{R} = \frac{100}{1} = 100 \text{ amperes.}$$

In the second or three wire system $R = \frac{200}{50} = 4$ ohms,

$$\text{and } C = \frac{E}{R} = \frac{200}{4} = 50 \text{ amperes.}$$

If these were the only considerations, the mains on the three wire system would, with equivalent lamps running, need to be only one half the sectional area of the mains on the parallel system.

None of these calculations, however, take in the third wire, and might just as well be comparisons between parallel and multiple series. The third wire would not be needed as a conductor to the dynamo if the lamps could always be exactly balanced as in the examples.

Suppose then c, k, e Fig. 115, represent 100 lamps, and g, m f represent 200 lamps, we have the pressure due to the combination of A and B supplying current for the 100 lamps c, k, e, and for 100 of the 200 g, m, f; the remainder of the current for the other 100 lamps g, m, f, will have to be supplied by B, that is, there will be a current from *s* along this third wire to make up the difference.

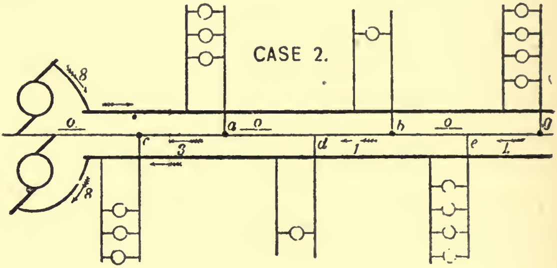


Fig. 117.

In practice a variety of cases can occur, and the intermediate wire must be of sufficient section to carry the maximum of difference current. This varies in different conditions, but if the theoretic maximum is taken, it will be when all the lamps are on one side and none on the other. When this provision is made, each of the three wires will have the same sectional area as would the conductors of the simple parallel system. In practice a difference of 25 per cent. is usually taken to guide in estimating the size of conductors, and usually the middle wire is given half the sectional area of either of the others.

In other cases the current will vary in different parts of the wire. An examination of the following illustrative

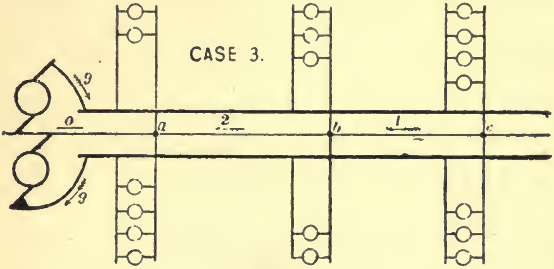


FIG 118

examples will show this. The small figures in the diagrams show how many lamps the current is for at that point.

In the first case Fig. 116, the grouping is symmetrical on

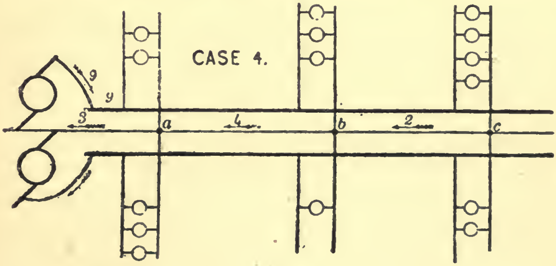


FIG. 119.

both sides, and the opposite groups are connected at the same points on the intermediate wire, which carries no current whatever.

In the second case Fig. 117, the groups remain the same but the points of connection are altered. The figures show how the current is carried.

In the third case Fig. 118, the total number on each side is the same but the grouping is different. The connecting points are the same, with the result as shown by the figures

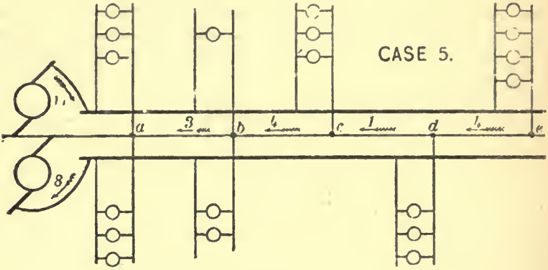


Fig. 120.

In the fourth case Fig. 119, the total numbers differ as does the grouping, but the groups are connected at the same points.

In the fifth and most practical case Fig. 120, the numbers and groups differ, and the connections are irregular.

An example of the system as applied by Edison will show conclusively that the actual gain by its use is far less than might at first sight be supposed. Fig 121, represents an underground installation. The central station is shown. The three wire distributing mains are shown laid on each side the street, but joined at convenient junction boxes 1, 2, 3, 4. Besides the distributing mains, feeders are taken to the junction boxes from the station. The whole forms a network, and should a feeder to any box be damaged, current is supplied from another direction.

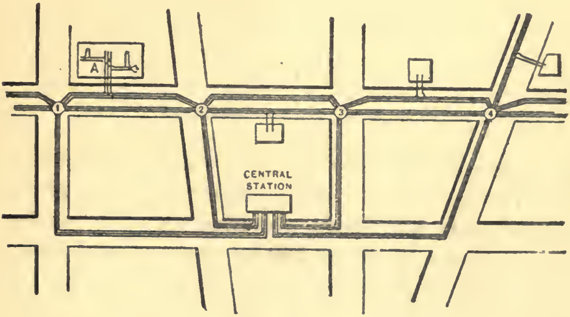


Fig. 121.

One of the most important practical questions is that concerning the economical section of wires for mains. Information on this subject will be found in Sir W. Thomson's paper to the British Association, 1881; and in Prof. G. Forbes, Cantor Lectures, 1885. In lighting it is important that the pressure remain constant, otherwise if it is too high the incandescent lamps supplied will soon be destroyed, if too low the light will be bad, inasmuch as the carbon filament of the lamp will not be raised to a sufficiently high temperature. The larger part of the electrical energy supplied to a lamp only suffices to raise the carbon to a red heat, the remainder raises is from red to white heat, the temperature in fact at which it radiates the desired light.

To secure perfect results the resistance of the mains must be so proportioned that the turning on or off lamps will not affect the current through those remaining in use.

CHAPTER VI

SIMPLE MEASUREMENTS.

In practical work connected with the three circuits described, measurements are necessary. Many of these measurements are simple, requiring only the reading of the deflection of a pointer moving over the graduated dial of the instrument. We must be satisfied with but a brief reference to this part of the subject, leaving the consideration of electro static measurements to more advanced books. It has been stated, on page 9, that certain practical units have been adopted, and it is necessary to be able to measure the number of units in any particular circuit.

Thus we have to measure **Current in Amperes.**

" " " " **Pressure in Volts.**

" " " " **Resistance in Ohms.**

How to Measure Current.—We have seen that if a small magnetic needle is brought near to a conductor carrying a current, the tendency of the needle is to set itself at right angles to that current. Different currents then can be compared by noting their effect upon a magnet, or they can be compared by noting their electrolytic action, or again by their heating action. The first method is that in general use.

If the conductor, supposed to be copper wire, and here-after called the wire, be bent into a circular shape, with radius of circle = r, then length of wire in circle l = 2 π r, and with current = C, the force acting at centre of circle,

$$F = C\frac{2\pi r}{r^2} = C\frac{2\pi}{r}$$

If a magnet pole of strength M be placed at the centre of the circle, the force will be represented by the product of the strength of pole and the intensity of the field, or

$$F = \frac{M\,C\,2\pi}{r}$$

It is impossible to have a magnet with only one pole, but we can approximate to the ideal by having a magnet relatively small to the radius of the coil in the centre of which it is suspended, the force exerted upon either pole by the current being then practically the same.

This is the principle adopted in the Tangent galvanometer.

The Tangent Galvanometer.—This instrument consists of a vertical ring of wire; in some instruments several coils of thick and thin wire. The thick coils are used for large currents, the thin coils are for use with smaller currents and can be used in series, in parallel or separately. The coils are carried on a base supported by levelling screws, so that they may be kept in a vertical plane irrespective of inequality of surface upon which the instrument stands. Fig. 122, shows one form of the instrument. At the centre of the coil, suspended on a delicate pivot or by a silk thread, is a small magnet, whose length should not be more than $\frac{1}{10}$ or $\frac{1}{12}$ of the diameter of the ring. The magnet carries a light pointer at right angles to its axis, so as to enable the graduated card just underneath the magnet to be easily read.

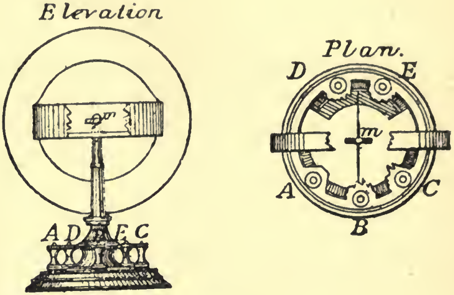


FIG. 122.

In setting up the instrument, the plane of the ring must be placed in the magnetic meridian, when the pointer should point to zero on the scale.

Since the magnetic field produced at the centre of the ring is very uniform, and the length of the magnet small in comparison to the radius of the coil, we may without serious error assume the poles to be at equal distances from the ring, whence a current through the wire will act upon each pole of the magnet with equal and opposite forces. The effect of this couple is to rotate the magnet round its point of suspension. When a current passes, the magnet is rotated through a deflection *d*. The extent of the rotation depends upon the ratio of the force due to the current in the coils, and the horizontal component of the earth's magnetism. In all questions relating to a magnet we must consider the effect of the earth's magnetism or in some way neutralise the effect. Roughly speaking, the earth acts as a magnet with its poles near to but not quite in the same direction as the geographical poles. The position of the earth's magnetic poles is constantly, though through small periods of time, slightly changing. Just as we term the imaginary lines passing through any place and through the geographical poles the geographical meridian of that place, so an imaginary line drawn through a place and through the earth's magnetic poles is called the magnetic meridian of that place. The action of the earth's magnetism upon the suspended needle is to direct the axis of the needle into a position parallel to the magnetic meridian, in other words to make the needle point north and south towards the north and south magnetic poles. If the needle be moved out of the meridian the horizontal intensity H of the earth's magnetism tends to pull it back into the plane of the meridian.

Now we are in a position to determine the law which governs the needle under the action of a current in the coil. It must be remembered that the action on one pole is equal and opposite to that on the other.

Let N S Fig. 123, represent the magnet in the plane of the coil, both magnet and coil being in the plane of the magnetic meridian.

Let $N_1 S_1$ be the new position of the magnet when a cnrrent is sent through the coil.

Let d be the angle through which the needle is deflected.

H as before is the horizontal intensity of the earth's magnetism.

Let F be the force due to the current.

Then the moment of couple due to earth's magnetism $= H \times AB$.

And the moment of couple due to current $= \text{F} \times \text{D E}$, but when the magnet is at rest these couples are equal.

$$\text{that is, } \text{F} \times \text{D E} = \text{H} \times \text{A B}$$

$$\text{whence } \text{F} = \text{H} \times \frac{\text{A B}}{\text{D E}}$$

$$= \text{H} \times \frac{\text{A O}}{\text{D O}}$$

$$= \text{H} \tan d$$

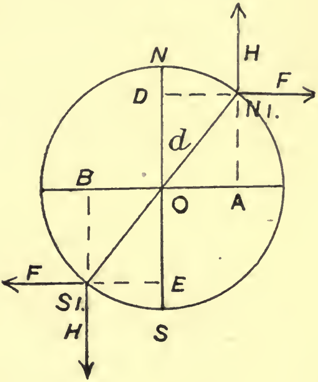


FIG. 123.

which gives the law :—

"The magnetic force which acting at right angles to the magnetic meridian produces on a magnet the deflection d is equal to the horizontal force of the earth's magnetism at that point multiplied by the tangent of the angle of deflection."

At any one place H may be taken as constant, hence the current varies as the tangent of the angle of deflection.

It must be noted that the strengths of current are relative only. Currents can thus be compared with one another.

In using a tangent galvanometer the aim should be to get deflections as near to 45° as possible, because this is the most sensitive deflection of the instrument. If two currents are to be compared, obtain deflections as near as possible at equal distances on the two sides of 45°. Thus if it is desired to get a current double of another, let the apparatus be so arranged as to give with the smaller current say a deflection of 30°.

$$\text{Tan of } 30^\circ = \cdot 5773503$$

A current of double strength will give a deflection in degrees of which

the tan $= 2 \times \cdot 5773503 = 1 \cdot 1547006$ or $46^\circ\ 6'$ nearly.

To obtain the value of the current in amperes we must know the constant of the galvanometer, which is $\frac{r}{2\,\pi}$ with one turn of wire in the coil, and $\frac{r}{2\,\pi\,n}$ with n turns in the coil; and divide by 10 because the practical unit of current is $\frac{1}{10}$ of the theoretical or absolute unit. The formula for amperes becomes

$$C = \frac{r}{2\,\pi\,n} H \tan d. \frac{1}{10}$$

Such a galvanometer as that described, however, is not suitable for engineering work.

Ampere-meters & Volt-meters.—Sir W. Thomson more than any man has placed the science and art of electrical measurements upon a firm footing. To him we owe our most accurate instruments, but the study of them and their applications is far outside the scope of this book, and we must be content to call attention to one or two of the instruments of less delicacy and beauty, such as are used in the rough and ready, everyday work of practical life. Marcel Deprez designed, and Ayrton and Perry improved the ampere-meters (generally called ammeters,) and voltmeters, so largely used in electrical engineering works. These are galvanometers in which the needle is made independent of the earth's action, by being controlled by the poles of a powerful, permanent or electro magnet, or by the pull of a spring, or by the action of gravity. The dials of most of these instruments are for direct reading, that is, a current of one, two, or ten amperes will move the indicator needle through one, two, or ten divisions of the scale. The ammeters are made with short coils of low resistance, and in sections which can by a turn of a con tact piece, be used in series or in parallel. Thus with a very strong current the coils would be used in multiple arc, but with weaker currents they would be used in

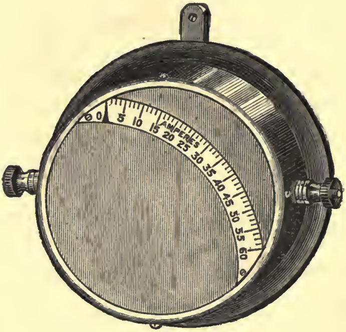


FIG. 124

series. These instruments can be used in any position, but with those controlled by permanent magnets, care has to be taken not to weaken the magnets or reverse them by the action of other and more powerful magnets near. This disadvantage is against the use of permanent magnets for controlling purpose, in that the sensibility of the instrument is very likely to be temporarily or even permanently varied by the action of powerful currents or magnets. Fig. 124, shows one of Pitkin's Ammeters, and

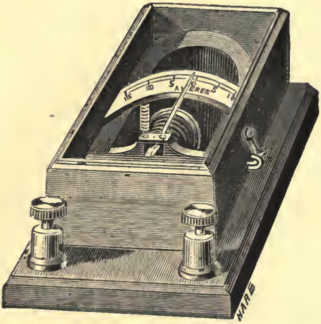


FIG. 125.

Fig. 125, shows one of Paterson and Cooper's, but of such Ammeters and Voltmeters their name is legion; they are similar in principle and roughly accurate in practise.

The divisions of the scale should be obtained by a careful calibration of the instrument, that is, should in the first instance be compared with a standard silver voltameter. An ampere of current will deposit .00111815 grammes of silver per second, and the current that will do this will give a deflection on the ammeter scale which should be marked 1 ampere; a current that will deposit twice this amount in a second, will give a deflection to be marked 2 amperes and so on. It does not follow that the scale divisions are equal. Usually, however, the scale is compared with another ammeter which has been duly calibrated.

The voltmeter differs from the ammeter in that the coils are of much greater resistance. The voltmeter, therefore, is an ammeter, but one measuring very small currents. Instead of measuring the whole current of a circuit, as does the ammeter, the voltmeter measures a very minute fraction of the total current, which fraction is taken as a by-pass through its high resistance coils from terminal to terminal of the mains to be tested. This minute current has no appreciable effect in lowering the pressure in the mains, and therefore any variation in this voltmeter current, must be due to alteration in the pressure in the mains and is, in fact, a measure of this alteration. Voltmeters should be provided with a key, and not used continuously, because the sensibility varies with the resistance, and the resistance alters on heating the coils.

Cardew Voltmeter.—The above mentioned instruments depending as they do upon electro-magnetic action will not measure alternate currents. An instrument designed by Captain Cardew, generally used for these measurements is a voltmeter which depends upon the heating property of the current for its utility. The elongation of a wire due to the heat is independent of the direction of the current and depends only upon the mean square of the current.

The instrument, Fig. 126, consists practically of a long platinum or suitable wire, rigidly fixed at one end, and fixed at the other end to a spring. When the wire

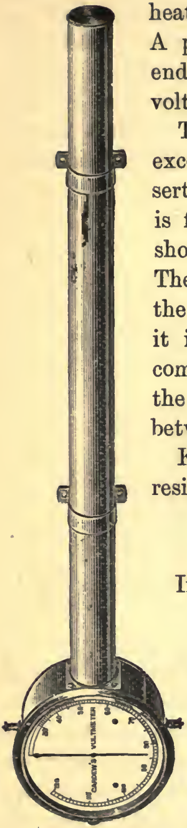


FIG. 126.

heated it lengthens, and the spring shortens. A pointer suitably arranged at the spring end moves over a dial graduated to show volts.

The use of ammeters and voltmeters is exceedingly simple. The ammeter is inserted in the circuit, and when a current is flowing; the deflections of the needle show the value of that current in amperes. The voltmeter should be connected with the two points whose difference of pressure it is required to know. Pressing the key completes its circuit, and the needle indicates the number of volts difference of pressure between the two points.

Knowing the amperes and the volts, the resistance of the circuit can be calculated,

$$\text{for } R = \frac{E}{C}$$

In many cases the electrical engineer is satisfied with this way of calculating resistance, but it is frequently necessary to take direct measurements of resistance. This requires other apparatus and will now receive a brief and elementary consideration. The student who desires to pursue the subject of measurement will find a number of admirable books to his hand; the subject really deserving and requiring a small treatise to itself.

The simplest method of determining resistance is to replace the unknown resistance by a known resistance.

Thus if we have a circuit containing a source of electrical energy, a galvanometer and an unknown resistance; upon a current flowing through the circuit the needle will be deflected. Note this deflection. Now take out the unknown resistance and connect in the circuit a known resistance that can be varied at will. Vary the resistance till the deflection of the galvanometer is again the same as before. Note this resistance, which will be the same as that displaced. Known resistances can be purchased in many arrangements. Fig. 127, shows how resistance coils or resistance boxes are constructed, *a a a a* are thick blocks of brass or suitable conducting metal, *f* is a plug the lower part of metal conical in shape to fit the conical holes bored in the blocks *a a*, the upper part *f* is of ebonite or some non-conducting material, *c c* is an insulating cover. Below the cover are shown three boxes of ebonite or other insulating material. Each box contains two thick

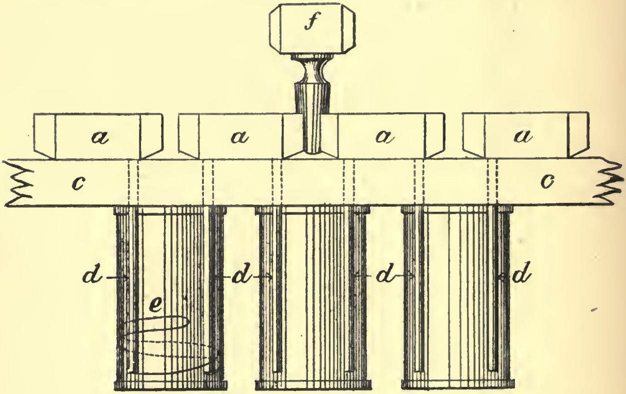


FIG. 127.

conducting rods *d d* going through holes in the cover *c*, one rod being connected to one end of a block *a*, the other rod similarly connected to the end of the next block *a*. The end of the rods in any one box are connected by a wire *e* whose resistance has been carefully measured by comparison with Standards. This wire is doubled on itself to prevent self-induction. The thick rods *d d* and the blocks *a a* should

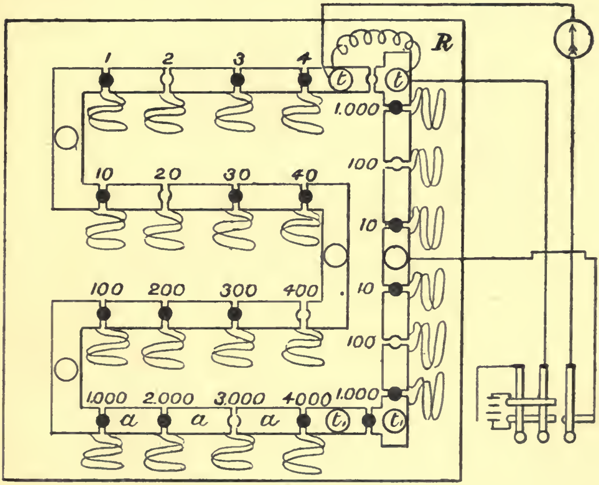


FIG. 128.

be massive enough to have no observable resistance. If now the boxes contain resistance respectively of 1, 2, 3 ohms and so on, we can substitute these known, for unknown resistances. In many cases the insulating boxes are not used, but a number of resistances are put into one box and separated by pouring in paraffin. When the plug *f* is out from two adjacent blocks the two resistances are in series, and by having a sufficient number of graduated resistances they can be arranged so as to give any total resistance up to the limits of the apparatus. Fig. 128, shows a common form of arrangement. The figures show the resistance of the particular coils, and the whole are arranged to be used as a Wheatstone bridge.

Wheatstone Bridge Method.—It is not very often convenient to replace the unknown by the known resistance, so a balancing method is used, first introduced by Gilbert, but made popular by Wheatstone, since called Wheatstone's bridge method. The arrangement is shown in Fig. 129. Let the four resistances *a*, *b*, *c*, *d*, be joined as shown at A B C D; while A and B are connected to battery E through key K_1 : and C D are connected to galvanometer G through Key K. Closing K_1 a current flows between A B through the branches *a b* and *c d*. If K is open,

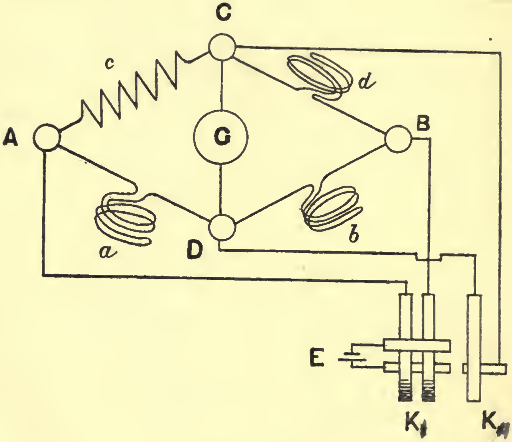


Fig. 129.

then whatever current goes through *a* will go through *b* ; similarly whatever current goes through *c* will go through *d*. If e_1 = pressure between A D ; e_2 that between D B ; e_3 that between A C ; and e_4 that between C B.

then current through *a* = current through *b* $= \frac{e_1}{a} = \frac{e_2}{b}$

" " *c* = " " $d = \frac{e_3}{c} = \frac{e_4}{d}$

Close K and suppose *no current* flows through the galvanometer, that shows $e_1 = e_3$, and $e_2 = e_4$;

$$\text{whence } \frac{e_1}{a} \times \frac{c}{e_3} = \frac{e_2}{b} \times \frac{d}{e_4}$$

$$\text{"} \qquad \frac{c}{a} = \frac{d}{b}$$

$$\text{or} \qquad c = a\frac{d}{b}$$

Thus if *c* is an unknown resistance, and *a* a known resistance, and $\frac{d}{b}$ a known ratio, we can calculate the resistance *c*.

In practise, then, we probably have some knowledge of the resistance to be measured, that is, we know it is small or large, and arrange the ratio suitably. In Fig. 128, the right side coils 10, 100, 1000 ; 10, 100, 1000 represent the resistances *b d*; R is the unknown resistance represented in the diagram by *c*, while *a* is indicated by the other resistances from 1 to 4000. The black dots represent plugs, and when plugs are in, that resistance is cut out of the circuit. In using resistances, care has to be taken that the current used is not too strong, otherwise the resistances or the insulation will be spoilt ; nor should the current be kept on, otherwise the coils will be heated, and the resistance will not be constant.

Here we must leave the reader. If this little book finds favour, its defects will be condoned, as it is an attempt in a somewhat novel direction.

Either the whole of electrical and magnetical phenomena can be explained by the circuits and their interactions or they cannot. The author believes they can, and by so doing practical calculations can be simplified.

RESPICE FINEM.

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